

THE BRITISH SOCIETY FOR THE PROMOTION
OF VEGETABLE RESEARCH

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Second
Annual Report
1951

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NATIONAL VEGETABLE RESEARCH
STATION

WELLESBOURNE - - WARWICK

Telephone : Wellesbourne 322

1952



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THE CONSTITUTION OF THE NATIONAL VEGETABLE RESEARCH STATION

The National Vegetable Research Station (N.V.R.S.) at Wellesbourne, Warwickshire and its Sub-Station at Paglesham, Essex, were established under a Governing Body incorporated on 28th September, 1949, as a company limited by guarantee, not having a share capital, and having the title "The British Society for the Promotion of Vegetable Research," with its registered office at Wellesbourne.

The members of the Governing Body, twenty-three in number, include nominees of the two Agricultural Departments of Great Britain, of the Department of Scientific and Industrial Research, of various learned societies, universities and institutions concerned with horticulture, of vegetable producers (through the National Farmers' Unions of the two countries and the National Allotments and Gardens Society) and of trade interests.

The properties at Wellesbourne and Paglesham are leased to the Society by the Ministry of Agriculture and Fisheries. At the outset the Society depends for its funds on grants from this Ministry, except that if any stations are established or work is conducted in Scotland, grants will be receivable also from the Scottish Agricultural Advisory Council. Both Agricultural Departments are advised by the Agricultural Research Council (A.R.C.) who have the scientific oversight of the work and staff.

GOVERNING MEMBERS OF THE SOCIETY

Appointed by the Minister of Agriculture and Fisheries :

Professor G. E. BLACKMAN, M.A., Department of Agriculture, University of Oxford.

Sir WILLIAM G. OGG, M.A., Ph.D., LL.D., Rothamsted Experimental Station, Harpenden, Herts.

Sir EDWARD J. SALISBURY, C.B.E., D.Sc., LL.D., F.R.S., F.L.S., Royal Botanic Gardens, Kew.

H. V. TAYLOR, Esq., C.B.E., D.Sc., A.R.C.S., V.M.H., Preston Grange, Ganwick, Potters Bar, Middlesex.

Appointed by the Secretary of State for Scotland :

R. L. SCARLETT, Esq., O.B.E., C.D.A., Sweethope, Musselburgh, Midlothian.

Appointed by the Department of Scientific and Industrial Research :

R. G. TOMKINS, Esq., M.A., Ph.D., Ditton Laboratory, East Malling, Kent.

Appointed by the University of London :

Professor J. W. MUNRO, C.B.E., M.A., D.Sc., Zoology Department, Imperial College of Science and Technology, South Kensington, London, S.W.7.

Appointed by the University of Reading :

Professor R. H. STOUGHTON, D.Sc., The University, Reading.

Appointed by the University of Cambridge :

Professor F. T. BROOKS, C.B.E., M.A., LL.D., F.R.S., F.L.S. (*Chairman*), The Botany School, Cambridge.

Appointed by the University of Bristol :

Professor T. WALLACE, C.B.E., M.C., D.Sc., F.R.I.C., The Research Station, Long Ashton, Bristol.

Appointed by the University of Edinburgh :

Professor S. J. WATSON, D.Sc., F.R.I.C., F.R.S.E., 57 Braid Avenue, Edinburgh, 10.

Appointed by the Royal Society :

Professor W. BROWN, M.A., D.Sc., F.R.S., 93 Church Road, Hanwell, London, W.7.

Appointed by the John Innes Horticultural Institution :

C. D. DARLINGTON, Esq., D.Sc., F.R.S., Bayfordbury, Herts.

Appointed by the National Farmers' Union :

- A. A. CLUCAS, Esq., Red Trees, Lathom, Ormskirk, Lancs.
 E. H. GARDENER, Esq., Steinbrook, Kington Langley, Nr. Chippenham, Wilts.
 G. G. HOLE, Esq., Argyll Lodge, South Avenue, Hurstpierpoint, Sussex.
 J. LAITY, Esq., Polkinghorne, Gwinear, Hayle, Cornwall.
 W. F. SWIFT, Esq., Avon Cottage, Fladbury, Pershore, Worcs.

Appointed by the National Farmers' Union of Scotland :

- DAVID LOWE, Esq., C.B.E., Elvingston, Gladsmuir, East Lothian.

Appointed by the Horticultural Trades' Association :

- J. S. W. CRACKNELL, Esq., V.M.H., c/o Watkins & Simpson Ltd., 27 Drury Lane, London, W.C.2.

Appointed by the Royal Horticultural Society :

- F. A. SECRETT, Esq., C.B.E., F.L.S., V.M.H., Hurst Farm, Milford, Godalming, Surrey.

Appointed by the National Allotments and Gardens Society :

- G. W. GILES, Esq., O.B.E., F.R.H.S., Drayton House, Gordon Street, London, W.C.1.

Appointed by the Seed Trade Association of the United Kingdom :

- A. L. DEAL, Esq., c/o W. W. Johnson & Son Ltd., Boston, Lincs.

The Executive Committee

- | | |
|-------------------------------------|--------------------------------------|
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| E. H. GARDENER, Esq. (until 7/5/51) | W. F. SWIFT, Esq. (from 8/5/51) |
| G. G. HOLE, Esq. | Dr. H. V. TAYLOR (<i>Chairman</i>) |
| | Professor T. WALLACE |

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| E. H. GARDENER, Esq. | Professor T. WALLACE |
| D. LOWE, Esq. | Professor S. J. WATSON |
| Professor J. W. MUNRO | |

Co-opted Member

- C. E. HUDSON, Esq., N.D.H., Ministry of Agriculture, 2 Cambridge Terrace, Regent's Park, London, N.W.1.

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(Chairman until 17/4/51)

W. F. SWIFT, Esq.

*(Chairman from 18/4/51)***Co-opted Members**

E. R. HOARE, Esq., B.Sc. (Eng.), A.M.I.E.E., Wrest Park, Silsoe, Beds.

H. W. HUGHES, Esq., The Moat Farm, Abbot's Salford, Warwickshire.

*(until 28/6/51)***Watercress Advisory Sub-Committee**

Professor W. BROWN

Dr. H. V. TAYLOR

Co-opted Members**Agricultural Research Council :**

G. G. SAMUEL, Esq., M.Sc., 15 Regent Street, London, S.W.1.

National Farmers' Union :

J. BIGGS, Esq., Quinar, Billington Lane, Sutton Scotney, Winchester.

Major CLIXBY-FITZWILLIAMS, Hazeldene, Healing, Nr. Grimsby, Lincs.

W. F. LYS, Esq., c/o Bedford & Jesty Ltd., Doddings, Wareham, Dorset.

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T. A. ROTHERHAM, Esq., c/o A. J. Edwards Ltd., Covent Garden,
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Road, Wye, Ashford, Kent.J. O. JONES, Esq., M.Sc., F.R.I.C., South-East Sub-Centre, Olantigh Road,
Wye, Ashford, Kent.W. E. H. HODSON, Esq., A.R.C.S., D.I.C., Provincial Entomologist, Chiltern
Court, Caversham, Reading, Berks.C. H. OLDHAM, Esq., N.D.H., Provincial Horticultural Advisor, The George,
Winchester.F. W. SHEPHERD, Esq., N.D.H.(Hons.), Rosewarne Experimental Horti-
culture Station, Camborne, Cornwall.

STAFF

Director :

JAMES PHILP, B.Sc. (Glas.), Ph.D. (Lond.), F.L.S.

Plant Breeding : D. BOYES, M.A. (Cantab), (Part-time, retired 30/9/51)
J. C. HAIGH, B.Sc. (Lond.), Ph.D. (Lond.), A.R.C.S., A.I.C.T.A.
(appointed 1/10/51)
G. D. SULLIVAN, B.Sc. (Wales)

Assistant : J. H. MATTHEWS

Entomology : D. W. WRIGHT, M.A. (Cantab)
J. A. DUNN, M.Sc. (Dunelm)
G. A. WHEATLEY, B.Sc. (Dunelm)

Assistants : H. I. SMITH
D. J. TWINN

Physiology : E. J. WINTER, M.C., M.Sc. (Bristol)
A. H. PARKINSON, B.Sc. (Reading), M.S. (Cornell),
Ph.D. (Lond.)

Assistant : Miss G. A. PURDY

Chemistry : R. M. WOODMAN, M.Sc. (Leeds), Ph.D. (Cantab),
F.R.I.C., F.Inst.P.

Assistants : T. W. G. McKEAN
Miss J. LAFFLING

Statistics : J. A. NELDER, B.A. (Cantab)

Watercress : D. M. SPENCER, B.Sc. (Wales)

Administration : *Secretary :* J. C. WILKINS, LL.B. (Lond.), A.C.I.S.

Accounts Clerk : J. H. L. BRIDGEWATER

Director's Personal Secretary : Miss E. L. D. DUNCAN
(resigned 11/7/51)

Clerical Assistants : Miss K. M. CREEK
(temporarily until 31/3/51)

Miss J. M. LAMB

Miss M. A. WARR

PROFESSOR F. T. BROOKS, C.B.E., F.R.S.

When Professor F. T. Brooks died on the night of Tuesday, 11th March, 1952, the Governors of the National Vegetable Research Station lost a wise Chairman, and the Station a great champion of research work.

Born and brought up in the rural county of Somerset, Brooks early gained an interest in garden and field plants, and this interest he retained throughout his life. As one instance one can cite his research into the fungus *Stereum purpureum* which showed it to be the causal organism of silver leaf of plum and other fruit trees, and his recommendation of good orchard hygiene for its control.

Of his great qualities and abilities in the scientific field I need not write but merely say they were considerable. From school he won a scholarship to Cambridge where his botanical studies took him from strength to strength ; Student, Research Worker, Demonstrator, Lecturer, and finally Professor. He made Cambridge a centre of botanical thought and study.

On his retirement from the Chair of Botany of Cambridge University he was elected Chairman (the first one) of Governors of the National Vegetable Research Station and soon won the respect and admiration of the Governors and staff of the Station. To the administrative problems Brooks brought a penetrating mind, and after a deep and thorough study, and with a well-balanced judgment he came to a decision. When a decision had been reached he was strong and firm in its execution. It was this method of working that won our respect.

To the casual observer his outlook might appear stern and severe, yet those who knew him better realised his finer qualities : loyalty, friendship, sympathy for the feelings of others, kindness to all engaged in research, and a great love of work. Underneath too there was real cheerfulness and many will remember his hearty laugh that broke out when least expected.

We Governors of the Station will ever remain grateful for his help as first Chairman in conducting the business of the Station during its early years, and are fully conscious of the difficulty of finding a worthy successor.

H. V. TAYLOR.

REPORT OF THE DIRECTOR

FARMING OPERATIONS

During the year 1950-51 farming operations were carried out entirely by the Station staff whereas in the previous year most of the work had been done by the Warwick County Agricultural Executive Committee on a contract basis. In anticipation of this changeover, implements and machinery had been bought and subsequent purchases were made as the need for additional equipment arose. Additions to the number of farm staff, however, could not be made easily, especially as housing accommodation could not be offered. Farm work throughout the year, therefore, was attended by the difficulties associated with shortage of staff. The Director was relieved of the burden of running the farm when Mr. T. J. Norwood took up his duties as Farm Manager on 1st April, 1951.

The wet autumn, winter and spring of 1950-51 and the resulting difficulties will long be remembered by farmers. The data from our Crop Weather Station show that during the months of November to March rain fell on 96 days with a total of 13.75 inches as compared with the long-term local average of about 9.35 inches. Transporting of root crops from and dung to the fields was a prolonged and difficult job especially as there were no internal roads on the farm. This defect was remedied later when some cinder roads were laid down as a temporary measure until concrete roads could be made in accordance with the development programme. A contract scheme for the draining of a portion of field 90 (Soakwaters) had to be postponed until the winter of 1951-52 owing to the land being waterlogged until well into 1951. The extremely wet season also showed that other parts of the farm needed draining and this work had to be done by the farm staff in portions of fields 101 (Sheep Pens) and 133 (Bungalow Field) in order to permit cultivation and sowing to be carried out. It also delayed other spring cultivations, sowing and planting.

Despite these difficulties, the cropping programme was carried out according to plan and, as was generally experienced, the resulting crops were better than had been expected. The cropping programme followed the agreed policy of building up soil fertility, cleaning the land and providing food for stock to produce dung. It takes some time to achieve the first two objects but it may fairly be said that the programme is beginning to show beneficial effects.

Vegetable production was a new experience for most of the farm staff and the practical technique of field experimentation was strange to all of them. A considerable amount of effort, therefore, went towards training them and supervising their work, especially in connection with research material where the necessary degree of care and accuracy is far beyond that required in commercial vegetable cultivation. Plans have been made for the installation of an irrigation system and it is noteworthy that the need for such a system was demonstrated in this, the first year's cropping of vegetables for research. The wet spring was followed by a dry period in June-July and, in order to transplant brassicas and keep them alive during this drought, water had to be carted to the field and applied by hand. Fortunately, the area was not large and could be dealt with in this way, otherwise valuable material and a year's progress in research would have been lost.

78 cattle were wintered in the yards and were summer-grazed on the leys, 40 being sold, fat, in August. The Station's silage, made in 1950, was awarded third prize in the Warwick County silage competition. The stockyards had concrete floors laid during the summer which will facilitate the removal of dung in future. A considerable amount of repair and maintenance work was done during the year.

At the sub-station at Paglesham, farming operations were done on a contract basis by the Agricultural Land Commission. The cropping programme was based on the same policy as for Wellesbourne but the adverse weather prevented green manuring from being carried out on 40 acres as planned. Repair work was carried out on some of the farm buildings.

DEVELOPMENT

In February 1951, permission was given for the sinking of a borehole on the Station and in April the Treasury gave its authority to proceed with this. A consulting engineer was appointed in May to prepare plans, specifications and bills of quantity for the sinking of the borehole and the installation of water mains, also sub-mains for irrigation, and to supervise operations. A contract was placed for the sinking of the borehole, a starting date was obtained and work began in November. Plans and specifications for the water mains and for irrigation sub-mains and equipment are being prepared and this work will follow the sinking of the borehole.

As pointed out in the previous Annual Report, the delay in obtaining permission to sink a borehole on the Station prevented the building plans, prepared in July 1950, from being submitted to the Treasury by the Ministry of Agriculture and Fisheries. In January 1951 it was agreed in the interests of national economy to amend the plans of the first phase of the building development scheme. The amendment involved postponement of some of the building development and alteration of some of the plans. Moreover, owing to the delay, plans for the fitting of a farm store for temporary use as laboratories had to be extended, and part of the scheme for experimental glasshouses had to be transferred from the second to the first phase of the development scheme. It was thus necessary to prepare revised estimates of costs of the immediate building proposals covering roads, services, farm buildings, temporary laboratories, houses and glasshouses. Treasury approval in principle to these proposals was obtained in April 1951, and work is due to begin on 1st May, 1952, which has been allocated as the starting date. Plans, specifications and bills of quantity have been prepared for an entrance road, farm roads, service roads to staff houses and glasshouses, main drainage, and sewage disposal works, and a contract is to be placed for this work to be started in May 1952. When this is underway, work will be started on the remainder of the first phase of the general development scheme.

Owing to the slow progress of the development programme, it was necessary to provide temporary expedients in order that research work could continue. Four second-hand wooden huts were erected by Station labour during the year, in addition to the two huts erected previously. One, 42×16 feet, was erected in January 1951, and three, 54×16 , 40×15 and 18×12 feet, were erected in September. Two of them were transferred from the Cambridge Horticultural Research Station (H.R.S.). These huts were fitted and equipped as laboratories and offices for research staff and also provided library and canteen facilities. Piped water was laid from a surface well to three of the huts which were also supplied with 'Calor' gas. Temporary glass-houses of the 'Dutch Light' type were erected for research purposes, one with heat.

During the summer an electric power line was laid to the entrance to the Station. The huts, farm buildings and a cottage were wired for electricity during September / October and were connected by underground cable to the main in December, thus ending a two-year period during which light and heat were provided by oil lamps and heaters.

Possession of a cottage on the property was obtained late in 1950. Renovations and alterations were carried out on the cottage but it was not ready for occupation until October 1951.

Work began in the spring of 1951 on the Stratford-on-Avon Rural District Council housing programme at Wellesbourne. The first portion of the scheme consisted of nineteen houses, nine or ten of which were to be rented by Station employees. The houses were completed at intervals from the end of September and Station staff moved into them as they became ready for occupation.

STAFF

No additions were made to the scientific staff during the past year because of the lack of laboratories and houses, but it is hoped that it will be possible to make some new appointments during the coming year.

Mr. T. J. Norwood took up his duties as Farm Manager on 1st April, 1951. He and his family lived in a caravan at the Station until October when they moved into a Station cottage which had been added to and renovated.

Miss J. M. Lamb was appointed as a clerical assistant on 23rd October, 1950. Miss K. M. Creek was appointed temporarily as a clerical assistant from 16th November, 1950, until 31st March, 1951. Miss E. L. D. Duncan was appointed as Director's Personal Secretary on 7th February, 1951, and resigned on 11th July, 1951. Miss M. A. Warr was appointed as a clerical assistant on 18th June, 1951.

Mr. J. A. Nelder, who had been provided with facilities for carrying out his work at the Statistical Department of Rothamsted Experimental Station, transferred to Wellesbourne on 1st January, 1951.

Messrs. D. Boyes, G. D. Sullivan (plant breeding), D. W. Wright, J. A. Dunn, G. A. Wheatley (entomology) and Dr. R. M. Woodman (chemistry) continued their work at Cambridge. Messrs. Sullivan, Wright, Dunn and Wheatley transferred to Wellesbourne in October 1951, also an assistant, Mr. H. I. Smith. Mr. Boyes, who had been employed on a temporary basis following his official retirement in September 1948, retired on 30th September, 1951, as arranged. The assistants, Messrs. J. H. Matthews, T. W. G. McKean, D. J. Twinn and Miss J. Laffling did not wish to transfer from Cambridge to Wellesbourne, and resigned on 30th September, 1951.

The grant provided by the A.R.C. for the strawberry breeding work carried out by Mr. Boyes (part time) and Mr. H. Williams, was administered by the N.V.R.S., until 30th September, 1951, when Mr. Boyes retired and Mr. Williams was transferred to continue the work at the John Innes Horticultural Institution, Bayfordbury, Hertford.

Dr. J. C. Haigh was appointed to take up his duties on 1st October, 1951, as successor to Mr. D. Boyes. Dr. Haigh was on the staff of the Scottish Society for Research in Plant Breeding and he has also had much experience of plant breeding abroad.

Dr. A. H. Parkinson worked at the Imperial College of Science and Technology, London, and was provided with land for experiments at the Royal Botanic Gardens, Kew. He transferred to Wellesbourne on 1st November, 1951.

Mr. D. M. Spencer continued his work on watercress diseases at the National Agricultural Advisory Service (N.A.A.S.) Sub-Centre, Wye, Kent.

Dr. A. H. Parkinson attended a Conference organised by the Society for Experimental Biology and held in Holland in April 1951. Messrs. D. W. Wright and J. A. Dunn attended the 9th International Congress of Entomology, held in Holland in August 1951.

RESEARCH

A Crop Weather Station was set up and started to function in October 1950. It forms one of the official network of such stations throughout the country whose results are co-ordinated by the Meteorological Office. The data provided by this station will be of great value for the research work. We have already co-operated with the Meteorological Office and the N.A.A.S. in determining the connection between weather conditions and the incidence of blight on potatoes, with the object of predicting when treatment against blight should be applied.

The first crops of vegetables for research purposes were grown on field 101 (Sheep Pens) which was netted to keep out rabbits. Adverse weather made it impossible to establish a few of the field experiments as planned. All the breeding material from Cambridge was grown at Wellesbourne except that which was seeding in 1951. The latter was grown at Cambridge and Paglesham. Some of the field experiments of the entomologists stationed temporarily at Cambridge were also carried out at Wellesbourne. These arrangements necessitated periodic visits by the staff from Cambridge to Wellesbourne. The season's work served to introduce the farm staff to the intricate work and careful attention which field experiments demand. Experience was thus gained which will be valuable for the future.

Good progress was made with the plant breeding work during the year. Selection was begun in Roscoff winter cauliflower and was continued within some promising new varieties of brassicas and onions. A wide range of varieties of Brussels sprouts were grown in Cardiganshire, where ring-spot disease is prevalent, in order to determine whether any varieties or individual plants showed resistance to the disease. Nucleus stock seed was produced of new varieties undergoing trial and of established varieties for further multiplication and distribution by the National Institute of Agricultural Botany (N.I.A.B.). A new variety of Brussels sprouts and two new varieties of winter cauliflower were distributed (through the N.I.A.B.) for the first time.

On the entomological side, it has been shown previously that cabbage root fly may considerably reduce the yield of certain brassica crops in the southern part of this country. Field experiments with summer cauliflower have confirmed this and have shown that the quality of the crop may also be adversely affected. Moreover, it was found that the degree of attack varied from year to year, and that the effect on the crop was not necessarily proportional to the degree of attack but depended largely on the rainfall during May and June. When the rainfall was low the adverse effect was considerable, but when it was high the effect was negligible; insecticidal treatment, therefore, gave good improvements in the yield and quality of the crop only when the rainfall in either May or June was low.

Dusts of low gamma BHC content, or five per cent. chlordane dust, applied by spoon around the stems, gave excellent control and were more effective than four per cent. calomel dust. Careful application of liquid forms of gamma BHC, chlordane or parathion to the base of the plants also gave excellent control. These liquid forms can be applied more precisely and more cheaply than dusts. None of the insecticides, as used, was found to harm the plants. They did not deter cabbage root flies from laying eggs around treated plants but they were very toxic to the unhatched and recently hatched larvae.

The seven spot ladybird is the most important predator of the pea aphid on perennial legume crops in the Eastern counties, because of its abundance and its appetite. A laboratory experiment has shown that there is a critical temperature of about 51-52°F. which affects the population balance of these insects. Below this temperature, the pea aphid population can increase in spite of the depletion by ladybirds; above this temperature, the ladybirds are potentially capable of reducing the

aphid population. Temperature is thus a factor connected with the marked increase of the aphid population on perennial legumes in spring and late autumn, and during cold periods in summer.

Progress has been made in the study of the basic properties of dusts in relation to the control of insects on vegetable crops, and of methods of formulating insecticidal dusts. It has been found that the effectiveness of DDT dusts for the control of pea aphids depends mainly on the aphids coming into contact with the dust while they wander over the plants, and only slightly on the dust deposited on the bodies of the insects during dusting. Pea aphids move around much more when the temperature is above about 65°F. and hence DDT dusts applied when the temperature is above 65°F. should give better control of the aphids. It has also been found that the degree of deposition of dust from a dust cloud on to a pea plant is dependent on the overall form and size of the plant, not on the variations in the size of the leaves or stipules. Further study may elucidate the optimum dusting rate for different crops, or may provide an understanding as to why different crops require different rates of dusting to give the same deposit on the plants.

Physiological studies were made of growth and flowering of cauliflower. Low temperature treatment of young plants had a small effect on subsequent growth and resulted in the cutting date being advanced by about four days. Plants grown to maturity in high temperature grew taller, their cutting date was later and their curd size was much reduced as compared with plants grown in the open at normal temperatures. Large pots, rich soil, or a high nitrogen level (in sand culture) gave a greater growth rate and curd size, and a much earlier cutting date than small pots, poor soil, or a low nitrogen level. Young plants which were subjected to drought, or were not pricked-off, or were damaged in planting, suffered an initial check in growth but they did not 'button.' Perhaps the treatments were given at too early a stage of development to produce 'buttoning.' They headed a few days later and gave slightly smaller curds than untreated control plants. Hearting and bolting of lettuce were delayed by close spacing, and by transplanting in June at the four-leaved stage or later.

In 1951, four rotations, each of four years with five vegetables, were completed in a manurial experiment on a light gravel soil at Cambridge, and a preliminary analysis of the results over the sixteen years has been made. The results indicated that Brussels sprouts were somewhat sensitive to the lack of potash which could be supplied either as fertiliser or in dung. Peas responded to fertiliser or dung, or to a combination of both but not to a great extent, and least of all to the application of nitrogen in the form of fertiliser or dung. A supply of phosphate, however, was beneficial. Lettuce did best with dung and full fertiliser treatment, nitrogen and potash being particularly helpful. After six years without dung or fertiliser, the lettuce crops failed. Spring cabbage also did best with dung and full fertiliser treatment and responded well to nitrogen and potash. With no manurial treatment, the yields fell quickly and reached zero during the last four years. It seemed that manurial treatment, especially potash, was beneficial to carrots.

A survey of watercress beds during two years showed that symptoms of crook root disease occurred in October, that plant vigour decreased until the end of March, and that recovery was general from April onwards. Laboratory experiments demonstrated that the disease was caused by a fungus which infected the roots. It was tentatively classified as a member of the *Plasmodiophorales*. The cycle of infection was completed in eight days thus accounting for the rapid spread of the disease in watercress beds. During late spring and summer, artificial infection could only be achieved if the plants were shaded from direct sunlight ; this helps to explain why the crop recovers during that period.

The green type of watercress is more tolerant of the disease than the brown, and well-grown cress is likewise more tolerant than poorly-grown cress. Glauconite

placed in an infected bed did not arrest the disease but those plants in the flow below the glauconite were more vigorous and were ready for cutting one month sooner than the rest of the crop. It appears that, in order to avoid the ravages of this disease, the crop should be well grown and vigorous, it should be started off in a clean bed with disease-free cuttings or from seed, and every precaution should be taken to prevent subsequent infection of the crop.

On the statistical side, assistance was given to research workers of the Station on experimental design, sampling technique and analysis of data. It was also arranged that the Station's statistical section would assist the N.A.A.S. Experimental Horticulture Stations and, so far as work permits, the Provincial Experiments Committee of the N.A.A.S. and other outside bodies with experimental designs and statistical matters concerned with experiments on horticultural crops, excluding fruit. A considerable amount of help was given in this connection during the year. A study was begun of statistical problems connected with the genetics of continuous variation, a phenomenon which is commonly associated with characters of economic value in crop plants.

Acknowledgments

Acknowledgments and thanks are due to the Imperial College of Science and Technology, London ; the N.A.A.S., Wye ; the Rothamsted Experimental Station, Harpenden ; the Royal Botanic Gardens, Kew ; and the School of Agriculture, Cambridge, for providing members of the staff with accommodation and facilities for their research.

Acknowledgment is also made to the Agricultural Land Commission for co-operating in carrying out the farming work at Paglesham.

Special thanks are due to the East Malling Research Station, Kent ; the Glasshouse Research Station, Cheshunt ; the Imperial College of Science and Technology, London ; the John Innes Horticultural Institution, Bayfordbury, Herts. ; the Long Ashton Research Station, Bristol ; the N.A.A.S. ; the National Institute of Agricultural Engineering, Wrest Park, Silsoe, Beds. ; the Horticultural Department, Reading University ; the Rothamsted Experimental Station, Harpenden, Herts. ; Messrs. Watkins and Simpson, Drury Lane, London, and other bodies for assistance in matters connected with the planning of the new development at Wellesbourne.

Thanks are also due to all those, especially growers and commercial firms, who have assisted the Station in many ways.

Mr. A. A. Clucas, a member of the Governing Body, has kindly given £500 to the Station to be used for any purpose which would not normally be provided for by grants from the Ministry or by other Government Funds, e.g., staff amenities. The Governing Body and the staff of the Station are grateful to Mr. Clucas and thank him for this generous gift. The Governing Body is establishing a Trust Fund into which this money will be placed.

Mr. D. Boyes is thanked for having continued his vegetable breeding work, as a part-time member of the staff, for two years beyond the time when he normally would have retired from his post as Director of the Cambridge H.R.S.—which coincided with the N.V.R.S. taking over the staff and work of the H.R.S. Thus, the plant breeding proceeded without interruption and he made it possible for his work and technique to be continued at Wellesbourne.

Some members of the staff carried out special duties in addition to their normal work and particular acknowledgment of this is made. Mr. Winter gave valuable assistance in connection with the planning of the new development scheme, and in supervising the erection and fitting of huts as temporary laboratories and offices ; he

also helped for some months with the running of the farm. Messrs. Wright, Dunn, Wheatley, Sullivan and Smith also did excellent work in connection with the transfer of all their equipment and plant material from Cambridge to Wellesbourne. Mr. Bridgewater organised and supervised the running of the canteen and Mr. Nelder assisted in the editing of this Annual Report.

Grateful acknowledgment is made to all the staff and employees for the loyal manner in which they have carried out their work, often under difficult conditions.

Special thanks are also due to the Executive Committee and the Sub-Committees and particularly to the Chairmen of these Committees for the unstinted assistance they have given.

National Vegetable Research Station,
Wellesbourne,
Warwick.

31st January, 1952.

J. PHILP,
Director.

It is with the deepest regret and sense of loss that my colleagues and I have learned of the death on 11th March, 1952, of the Chairman of our Governing Body and Staff and Research Sub-Committee, and we wish to record our appreciation of the work he has done for the Station and for us. Professor Brooks took a most active interest in the development of the Station, and in our work and welfare. Everything he did for us, he did thoroughly and willingly. He set us a high standard and he helped us towards achieving it by giving generously of his time and effort, despite his numerous duties and responsibilities in connection with research elsewhere. He was always glad to let us draw on his great knowledge and experience, and on his wise counsel, and we readily took advantage of this. Although he has not been spared to see the Station a fully going concern, as he would dearly have loved, he saw to it that the Station made a sound beginning and thus he provided a pattern for future development. We are grateful to have been so closely associated with him and to have served under him ; we will remember him.

J. PHILP,

13th March, 1952.

PLANT BREEDING REPORT

By D. BOYES

During the year, plant breeding operations were mainly carried out at Cambridge, though a start was made at Wellesbourne and the work at Paglesham was extended.

Nucleus stock seed was produced of the varieties listed below :—

Varieties which have been distributed

Brussels Sprouts	..	Cambridge No. 1 (at Paglesham)
		Cambridge No. 3 (at Cambridge)
Winter Cauliflower	..	Cambridge (X10) Dwarf April (at Cambridge)
Onions	..	Cambridge Nos. 2 and 10 (at Cambridge)

Varieties, trials of which are not yet completed

Cabbage	..	Cambridge Red (at Cambridge)
Onions	..	Cambridge No. 1 (at Paglesham)

Promising varieties not yet tested in trials

Winter Cauliflower	..	Cambridge X12 (at Cambridge)
Onions	..	Cambridge Nos. 28 and 33 (at Cambridge).

Seed was produced of breeding material of Brussels sprouts and winter cauliflower at Cambridge ; onions at Cambridge and Wellesbourne ; and peas at Wellesbourne.

Progenies derived from crosses between plants drawn from different varieties of Cambridge sprouts have proved superior to either of the parent varieties involved. This year it was seen that these 'single crosses' were also clearly superior to progenies derived from 'double crosses' between individuals from different 'single crosses,' and that the 'double crosses' were slightly better than the parent varieties.

Work on the production of winter cauliflower with distinctive seed character was continued, and seed produced from a small mass selection was found to be true to the type.

Plants were grown for selection and the production of nucleus stock seed in 1952 of the following stocks :

Brussels Sprouts	..	Cambridge No. 5 (at Paglesham)
		Cambridge Special (at Wellesbourne)
Cabbage	..	Cambridge Drumhead (at Wellesbourne)
		Cambridge February (at Wellesbourne)
Winter Cauliflower	..	Cambridge (X10) Dwarf April (at Wellesbourne)
		Cambridge (MX) Hardy Late (at Paglesham)
Onions	..	Cambridge Nos. 1 and 2 (at Paglesham)
		Cambridge Nos. 10, 28 and 33 (at Wellesbourne).

Plots were also laid down at Wellesbourne in 1951 for the maintenance of breeding lines of Brussels sprouts, winter cabbage, winter cauliflower, peas and onions ; and of carrots at Paglesham.

As in previous years, nucleus stock seed of the Cambridge varieties of vegetables was supplied to the N.I.A.B. for multiplication and subsequent distribution. Assistance was given with inspection and roguing of the seed crops. Three new and recently distributed varieties featured among the latter, viz.,

Brussels Sprouts	..	Cambridge Special
Winter Cauliflower	..	Cambridge (MX) Hardy Late Cambridge (X10) Dwarf April

Notes on these varieties were included in the N.V.R.S. Annual Report 1949-50.

Work at outside centres

In order to begin a new breeding programme with Roscoff winter cauliflower, all the lines selected from the material originally introduced from Brittany were grown at the N.A.A.S. Experimental Horticulture Station, Brownwich Farm, Hants. Several hundred plants of distinct and desirable types were selected in the winter of 1950 and seeded in isolation during the summer of 1951. We are grateful to Mr. P. H. Brown, Director of the Station, and to Mr. C. H. Oldham of the N.A.A.S., for assistance with the planting, selection and harvesting of the crop.

In Wales and S.W. England severe attacks of ring-spot caused by *Mycosphaerella brassicicola* often result in serious losses in brassica crops in general, and Brussels sprouts in particular. The Roscoff type winter cauliflower and a type of cattle cabbage are known to be highly resistant to ring-spot, but it is not known if such resistance exists in sprouts. In the hope of finding such resistance, plots of English and continental varieties of sprouts were laid down in 1950 at the N.A.A.S. Station at Trawscoed, Cardiganshire. Despite the mild and extremely wet autumn and winter of 1950-51, however, little disease developed, and more comprehensive trials were planted in Wales and S. Devon in the spring of 1951. The co-operation of local N.A.A.S. officers in the planting and recording of these trials is gratefully acknowledged.

CONTRIBUTIONS TO THE BIONOMICS AND CONTROL OF THE CABBAGE ROOT FLY

(*Erioischia brassicae* Bché.)

By D. W. WRIGHT

INTRODUCTION

The cabbage root fly is a pest of considerable economic importance to growers of brassica crops, particularly in the southern part of Great Britain. The damage caused to the root system of the plant by the larvae and the effect on the growth and appearance of the crop have been described by many observers. It has been shown by the writer (1) (2) that, except in very severe attacks, the loss in crop yield attributable to this insect is not wholly measured by the proportion of the plants killed or severely stunted. Generally, the root system is not critically damaged but the plants, although not obviously distressed, give a reduced yield. He also showed that a well developed and undamaged root system is essential in dry seasons if the crop is to make the maximum response to inorganic fertiliser.

Following the development in 1938-9 of the 4 per cent. calomel dust treatment for the control of cabbage root fly, randomised block experiments with at least four replications have been carried out annually at the Horticultural Research Station, Cambridge. These have given a considerable amount of data upon the effect of this pest on crop yield and quality, on the yearly variation in the incidence of its attack, and upon the performance of the calomel dust treatment. With the advent in more recent years of the synthetic organic insecticides, many formulations and methods of application of these have been tested. The experimental crop used throughout was early cauliflowers which were raised in frames and transplanted in early April. The data given relate to the incidence of the first generation of this insect on the same crop and in the same locality. In 1951, however, field experiments were also carried out on cabbage at the N.V.R.S., Wellesbourne.

The effect of cabbage root fly attack on the yield and quality of early cauliflowers

Records were obtained in 1939, 1940 and 1945 of the yields from untreated and calomel treated plots. In addition, the cauliflower heads were graded for size and quality, and the results obtained are shown in Table I.

TABLE I

Improvements in yield and quality of early cauliflowers resulting from treatment with 4 per cent. calomel dust, Cambridge

	1939		1940		1945	
	Treated	Untreated	Treated	Untreated	Treated	Untreated
Per cent. increase in total yield compared with untreated crop	83.5	—	110.4	—	49.4	—
Per cent. increase in number of first grade heads compared with untreated crop	184.4	—	229.1	—	142.1	—
Per cent. of first grade heads ..	71.1	30.6	46.2	17.1	63.9	26.4
Per cent. of second grade heads ..	25.6	57.1	46.2	40.7	27.8	25.0
Per cent. of third grade heads ..	3.3	12.3	7.6	42.2	8.3	48.6

The infestation in any of these years was not rated as severe since less than 15 per cent. of the plants on the untreated plots were killed. However, very considerable improvement in vigour and uniformity of the crop resulted from treatment and this was reflected in the yield and quality data. The increase in yield following calomel treatment in certain other years can also be seen in Table II.

Relationship between rainfall, root infestation and increase in yield following calomel treatments

The levels of root fly infestation on treated and untreated early cauliflowers in randomised block experiments carried out at Cambridge over the period 1939 to 1951 are shown in Table II. Where yield data were also obtained, the comparative increases resulting from the calomel treatment are given. The Table also gives the rainfall for May and June of each year and the average monthly rainfall for these months.

TABLE II

Relationship between rainfall, increase in yield following calomel dust treatment,
and severity of root infestation of early cauliflowers, Cambridge 1939-51

Year	Rainfall		Per cent. increase in yield following use of calomel dust		Per cent. of roots severely infested	
	May	June			Calomel treated	Untreated
1939 ..	1.68	1.57	62.2	Trial I	4.4	85.6
1939 ..	1.68	1.57	83.5	Trial II	3.0	95.0
1940 ..	1.98	0.43	110.4		3.0	94.0
1941 ..	1.73	1.02	—		2.7	81.3
1942 ..	2.10	0.46	—		0.6	79.2
1943 ..	1.71	1.93	—		—	—
1944 ..	0.94	1.25	—		—	—
1945 ..	1.95	1.63	49.4		4.2	73.6
1946 ..	2.06	3.05	—		—	—
1947 ..	0.35	2.89	—		—	—
1948 ..	3.10	3.02	1.1		1.2	63.3
1949 ..	2.55	1.25	88.5		8.4	100.0
1950 ..	3.13	1.25	—		0	58.3
1951 ..	2.52	1.31	46.5		1.7	90.0
1939-51 Average ..	1.98	1.62				

After the crop had been harvested, the root systems were examined and graded according to the degree of root fly damage, using a standard system of grading from year to year. It will be seen that the natural incidence of attack, as measured by the severity of damage on the untreated plots, shows considerable variation from year to year. These fluctuations are probably largely due to biological factors such as parasites and predators, and do not appear to be correlated with the amount of rainfall in May and June, the main period of infestation and crop growth (cf. 1949 and 1950 in Table II). The extent of the increase in crop yield resulting from the calomel dust treatment, however, shows a significant negative correlation (-0.87) with the rainfall in these months. Thus in 1939, 1940 and 1949, following a low rainfall in June, considerable crop increases were recorded. Similar differences between treated and untreated crops were observed in 1941, 1942 and 1947, the rainfall in either May or June of each year being low. When the rainfall in both these months was well above normal, however, as in 1946 and 1948, there was no visible or significant improvement following treatment, growth in all cases being equally vigorous.

It would seem that under dry conditions in the soil, a damaged root system is unable to provide the plant with an adequate supply of water. The plant then wilts rapidly and the foliage takes on a highly waxed and leaden appearance, all of which are symptoms of water shortage. Where soil water is abundant, however, the damaged plant has comparatively little difficulty in making good its moisture requirements. It follows that in soils with a high moisture retaining capacity, plants damaged by root fly have the best opportunity of overcoming this handicap.

Relationship between degree of root infestation and yield of summer cabbage, 'Primo'

It has been shown that the effect of a given level of cabbage root fly infestation on crop yield varies from season to season and is probably directly related to the amount of water available in the soil during the growing period of the crop. It is not permissible, therefore, to compare different treatments by measuring their effects on yields, if these treatments have been included in experiments carried out either in different years, or at different times or places in the same year. In such circumstances moisture conditions in the soil and hence the response of the crop would be unlikely to be similar for any two cases. In any one experiment, however, the relative performance of various treatments can be ascertained through their effects on yield, since the latter bear a direct relationship to the infestations occurring on the roots. Table III shows the relation between root infestation and yield in an experiment carried out on summer cabbage at Wellesbourne.

TABLE III

Relationship between yield and root infestation in summer cabbage,
Wellesbourne, 1951

Treatment	Rate of application per 4,840 plants	Yield, tons per acre	Per cent. of root systems	
			Uninfested	Severely infested
1. 4% calomel dust ..	45 lb.	12.5	31.5	33.0
2. 0.17% gamma BHC dust	45 lb.	14.4	90.5	3.0
3. 0.45% gamma BHC dust	17 lb.	13.8	94.0	1.0
4. 0.45% gamma BHC dust	34 lb.	14.1	91.5	4.0
5. 0.005% gamma BHC suspension ..	$\frac{1}{4}$ pint per plant	13.8	68.5	12.5
6. 0.01% gamma BHC suspension ..	$\frac{1}{8}$ pint per plant	13.6	82.0	6.0
7. Untreated	—	11.5	1.5	79.0

Treatments 1, 2 and 3 applied by spoon, treatment 4 by hand duster.

Significant differences between treatments at the 5 per cent. level are as follows :—

Yield

7 < all others ; 1 < 2 to 6 ; no differences between 2 to 6.

Uninfested Roots

7 < all others ; 1 < 2 to 6 ; 5 < 2, 3 and 4 ; 6 < 4 ; no differences between 2, 3 and 4.

Severely infested roots

7 > all others ; 1 > 2 to 6 ; 5 > 2, 3 and 4 ; 6 > 3 ; no differences between 2, 3 and 4.

Treatments 1 and 7, assessed either in relation to yield or to unattacked or severely attacked root systems, gave performances significantly different both from each other and from the remaining treatments. The yield data for the remaining treatments (2 to 6), however, showed no significant differences but further differences appeared in the root infestation data. Other cabbage root fly experiments have also shown that root infestation data are more sensitive than yield data for assessing differences in performance between treatments. Furthermore, the root infestation method is the only one that can be used in wet seasons.

Other insecticides for the control of cabbage root fly

In field experiments over the period 1939 to 1951, 4 per cent. calomel dust gave a consistently high level of control (see Table II). However, since the control was usually not complete and the cost of calomel had increased greatly over the period, a number of the newer synthetic insecticides have been tested against this pest as possible substitutes for calomel.

Field experiments carried out during 1943 to 1946 showed that 5 per cent. DDT dust applied to the base of the plant as for calomel dust and at rates of 30 lb. to 40 lb. per 4,840 plants, gave only a partial and poor control. Used at rates of 15 lb. or less per 4,840 plants, the dust gave no detectable control and in one case caused a significant increase in infestation. The latter effect may well have been due to the DDT, at the lower levels of application, having been proportionately more toxic to the parasites and predators of the root fly than to the pest itself. An increase in infestation following the use of DDT has also been reported by Crowell *et al.* (3). DDT dusts and pastes applied to the stem and root systems before transplanting, and DDT emulsions applied afterwards, were all found to be only partially effective.

The insecticidal materials tested in five field experiments in 1951 for the control of root fly are shown in Tables IV and V. Their effectiveness, measured by the percentage of seriously damaged roots, is also given.

The following are the more outstanding results from the experiments summarised in Table IV.

- (i) Dusts containing 0.17 per cent. and 0.45 per cent. gamma BHC, used at the same gamma rate per 4,840 plants and applied by spoon to the base of the plant, gave similar and very high levels of control (Experiment I, treatments 2 and 4). The 0.45 per cent. gamma BHC dust applied at double this rate by hand duster appeared to have given a much less satisfactory control but the difference was not statistically significant. Using 4 per cent. calomel dust, however, significant differences have been previously obtained in the level of control between the spoon and hand duster methods of application. There is little doubt that with BHC dusts also, the hand duster is the less accurate method of placing the dust at the base of the plant.

In 1949 and 1950, BHC dusts used at rates to give the same dosage of gamma isomer as in the above treatments gave very high levels of control and, as in 1951, gave results superior to those obtained from the standard calomel dust treatment.

TABLE IV

Control of cabbage root fly by insecticidal dust treatments, 1951

A. PLANT TREATMENTS				Per cent. of root systems severely infested				
Dust Insecticide	Dust rate per 4,840 plants lb.	Rate of toxic principal per 4,840 plants	Method of application	Experiment number				
				I	II	III	IV	V
1. 4% calomel ..	45	1.8 lb.	spoon	33.0	1.7	—	—	0
2. 0.17% gamma BHC ..	46	1.27 oz.	spoon	3.0	—	—	—	—
3. 0.45% gamma BHC ..	18.3	1.37 oz.	duster	—	—	—	12.0	—
4. 0.45% gamma BHC ..	17.0	1.27 oz.	spoon	1.0	—	6.2	—	0
5. 0.45% gamma BHC ..	34.0	2.54 oz.	duster	8.5	—	—	—	—
6. 5% chlordane	30.0	1.5 lb.	spoon	—	—	0	1.5	0
7. 5% toxophene	30.0	1.5 lb.	spoon	—	—	—	—	11.3
B. BROADCAST TREATMENTS								
Dust Insecticide	Dust rate per acre lb.	Rate of toxic principal per acre lb.						
8. 0.45% gamma BHC ..	222	1.0	broadcast	—	38.3	—	—	—
9. 0.45% gamma BHC ..	444	2.0	broadcast	—	23.3	—	—	—
10. 0.45% gamma BHC ..	444	2.0	broadcast	—	41.7	—	—	—
C. CONTROL (Untreated)								
	—	—	—	79.0	90.0	100.0	75.5	32.5

Treatments 8 and 9 broadcast and raked in 1 day before transplanting.

Treatment 10 broadcast and raked in 12 days before transplanting.

Key to experiment numbers : I = summer cabbage, Wellesbourne ;
 II = early cauliflowers, Cambridge ;
 III = spring cabbage, Cambridge ;
 IV = autumn cauliflowers, Wellesbourne ;
 V = autumn cauliflowers, Cambridge.

- (ii) Dusts containing gamma BHC which were broadcast and raked into the top two inches of soil before transplanting at rates of 1 lb. and 2 lb. gamma isomer per acre, gave only a partial root fly control (Experiment II, treatments 8, 9 and 10). Similarly, imperfect control was obtained with BHC applied in this way in 1949 and 1950. Good control, however, was obtained by Stitt and Eide (4) in the U.S.A. with gamma BHC applied in the same way at the rate of 2 lb. per acre.
- (iii) 5 per cent. chlordane dust applied at 30 lb. per 4,840 plants gave an almost perfect control in each of three experiments (Experiments III, IV and V, treatment 6) and was the most consistently effective treatment used in 1951.
- (iv) 5 per cent. toxophene dust used at 30 lb. per 4,840 plants was tested in only one experiment (Experiment V, treatment 7) and gave results inferior to those of chlordane, BHC and 4 per cent. calomel dusts.

Unsatisfactory results have also been obtained with toxophene in the U.S.A. against this pest (4).

Insecticides were also used in aqueous form in certain of the 1951 experiments ; details of the materials used and the results obtained are given in Table V. The more important findings from these may be summarised as follows :—

- (1) Suspensions of gamma BHC and chlordane and an emulsion of parathion gave similar and very high levels of control in each case. (Experiment IV, treatments 1, 4 and 5). Their performance was not significantly different from that given by 5 per cent. chlordane dust (Table IV, treatment 6) but was better than that given by 0.45 per cent. gamma BHC dust applied by hand duster.
- (2) Where gamma BHC suspension was used at two concentrations (the amount of toxicant per plant remaining the same), the higher concentration appeared to be the more effective. The difference, however, just failed to reach statistical significance.

None of the materials used as described in the 1951 experiments, whether in aqueous or dust formulation, was observed to be phytocidal.

Mode of action

In developing methods of control, a precise knowledge of the stage of the insect which is being affected and the mode of action of the insecticide is of the utmost importance. It has been shown that calomel achieves its effect against the cabbage root fly, not by a deterrent action against the adults, but as an ovicide (1).

TABLE V

Control of cabbage root fly by insecticidal liquid treatments, 1951

Liquid material	Liquid rate per plant pint	Rate of toxic principal per 4,840 plants	Per cent. of root systems severely infested		
			Experiment number		
			I	IV	V
1. 0.005% gamma BHC suspension	$\frac{1}{4}$	1.27 oz.	12.5	4.0	—
2. 0.01% gamma BHC suspension	$\frac{1}{8}$	1.27 oz.	6.0	—	—
3. 0.15% chlordane suspension	$\frac{1}{4}$	2.25 lb.	—	—	0
4. 0.1% chlordane suspension	$\frac{1}{4}$	1.5 lb.	—	6.0	—
5. 0.025% parathion emulsion	$\frac{1}{4}$	6.0 oz.	—	2.5	—
6. Untreated	—	—	79.0	75.5	32.5

Liquids applied from measures by hand.

For key to experiment numbers, see Table IV.

Observations in the field have shown that BHC, chlordane, DDT and parathion are likewise not adult deterrents since the number of eggs deposited around brassica plants treated with these insecticides and those untreated were not appreciably different. To assess the effect of these insecticides against the egg stage, a series of replicated experiments were carried out in the laboratory using batches of root fly eggs of known age. Some 3 per cent. to 5 per cent. of the eggs proved infertile and were not included in survival counts. The results may be summarised as follows.

- (i) With 0.005 per cent. gamma BHC suspension, all the eggs developed to maturity but approximately 50 per cent. of the larvae failed to leave the eggs. The larvae which emerged died near the egg shells or after wandering a short distance.

With 0.01 per cent. gamma BHC suspension, all the eggs became fully embryonated as before but over 90 per cent. failed to hatch. Those larvae which emerged died nearby. A similar result was obtained with 0.45 per cent. gamma BHC dust.

- (ii) With 0.025 per cent. parathion emulsion, all the eggs became fully embryonated but less than 7 per cent. hatched; the larvae from the latter died near their egg shells.
- (iii) With 4 per cent. DDT dust, a complete egg hatch occurred. The larval mortality was partial and very variable, and many larvae wandered over the moist insecticidal dust for up to 24 hours before succumbing.

No tests were done with chlordane. Untreated eggs gave a 95 to 97 per cent. hatch and the larvae remained alive under the conditions of the experiment for a minimum of 36 hours.

DISCUSSION

Treatment of the transplanted brassica crop for the control of root fly, whether carried out by dust or liquid materials, must be done accurately if a considerable wastage of insecticide is to be avoided. The application of dusts, either by machines of the piston type or by hand, is liable to be an arduous, time consuming and therefore expensive procedure. Where liquids may be used, however, their application can be precise and more easily mechanised, and the cost correspondingly reduced. A lance with a spring loaded trigger tap and a coarse nozzle may be used to deliver the correct volume of liquid, with accuracy, at the base of the plants. The solution may be carried in a knapsack sprayer or, for large scale work, may be hauled in a spray tank and should be delivered at low pressure to prevent washing away of the soil from the plants and waste of solution.

Whereas calomel can be readily formulated only as a dust, BHC, chlordane and parathion may all be satisfactorily used in solution. Parathion, being intensely poisonous to mammals, should be handled with great care and prolonged contact of the dilute solution with the skin, through dripping taps, etc., must be strictly avoided. BHC and chlordane are much less poisonous than parathion and, in addition, it appears probable that both may be used at higher concentrations than in the present experiments without causing phytocidal effects. Thus it may be possible to reduce the quantity of liquid applied, but at least 40 to 50 c.c. per plant (nearly $\frac{1}{8}$ pint) appears to be necessary to wet the soil around the stem where the eggs are laid.

SUMMARY

1. Experiments have shown that considerable reduction in both the yield and quality of cauliflower crops may result from the attack of the cabbage root fly.
2. Records taken over the period 1939 to 1951 showed considerable annual variation in the incidence of attack of this insect.
3. The extent of the damage caused to early cauliflowers, as measured by the loss in yield, could not be related directly to the degree of attack but depended on the rainfall in May and June, when the crop was being subjected to attack by this pest.
4. Field experiments carried out in 1951 showed that dusts of low gamma BHC content, applied around the stems of the transplanted crop, gave very high levels of control and were more effective than 4 per cent. calomel dust similarly used. A 5 per cent. chlordane dust likewise gave excellent results.
5. Gamma BHC dusts, broadcast at high rates per acre and raked into the soil before transplanting, gave very imperfect control.
6. Liquid formulations of gamma BHC, chlordane and parathion, applied carefully to the base of the plant, were all very highly effective.
7. Field observations showed that neither gamma BHC, chlordane nor parathion deterred adults from ovipositing around treated plants, whilst laboratory tests showed that certain of these chemicals were very toxic to the unhatched and recently hatched larvae of this insect.
8. Certain advantages of liquid insecticides over dust insecticides for the control of this pest are pointed out, and methods of applying the liquid materials are outlined.

ACKNOWLEDGMENTS

The writer wishes to acknowledge considerable assistance given by Mr. H. I. Smith in carrying out these experiments. Thanks are due to Councillor Doggett of Cambridge for the rainfall data and Messrs. Plant Protection Ltd. for supplying the BHC materials.

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THE EFFECT OF TEMPERATURE ON THE PEA APHID—LADYBIRD RELATIONSHIP

By J. A. DUNN

In lucerne, trefoil and sainfoin crops in the Eastern counties, the most important predators of the pea aphid (*Acyrtosiphon pisum* Harris) are ladybirds, and of these the seven spot ladybird (*Coccinella septempunctata* Linn.) is the most common. It is also the largest species and, as the daily food consumption of a ladybird is related to its size, *C. septempunctata* adults eat more aphids per individual, per day, than do any of the other coccinellids. It is, therefore, the most important predator not only because of its abundance but also on account of its high feeding potential.

Several workers have studied the food consumption of ladybirds. Feeding records of many Californian Coccinellidae have been given by Clausen (1), and Fluke (2), also in North America, has given the diet of four species of ladybirds in terms of pea aphids. The numbers of aphids consumed by the larvae and adults of *Coccinella septempunctata* in India have been given by Bagal and Trehan (3), and the writer (4) has also recorded the numbers of *Macrosiphum solanifolii* Ashm. eaten throughout the larval stage. In none of these studies, however, does the effect of temperature on aphid-ladybird relationship appear to have been investigated.

With certain parasites and their hosts it has been found that the temperature ranges over which they are active do not necessarily coincide. Temperature, therefore, might be expected to affect aphid and predator populations differently. In view of this, an experiment was carried out in 1951 to determine the reproductive capacity of viviparous female pea aphids and the aphid consumption of the seven spot ladybird at different temperatures.

Methods

Ten ladybirds of similar origin were kept separately in 3×1 inch tubes at each of four different constant temperatures, namely 41°F., 50°F., 58°F., and 68°F. These were supplied daily with fresh, fourth instar, pea aphid nymphs and the number of aphids consumed in each twenty-four hours was recorded.

A second series of similar tubes was kept at 41°F., 50°F., 58°F., and 70°F. Each tube contained five freshly matured, apterous, viviparous pea aphids in a full and vigorous reproductive condition. The tubes were recharged daily with fresh, medium-sized leaflets of beans, and the aphid progeny were recorded and removed.

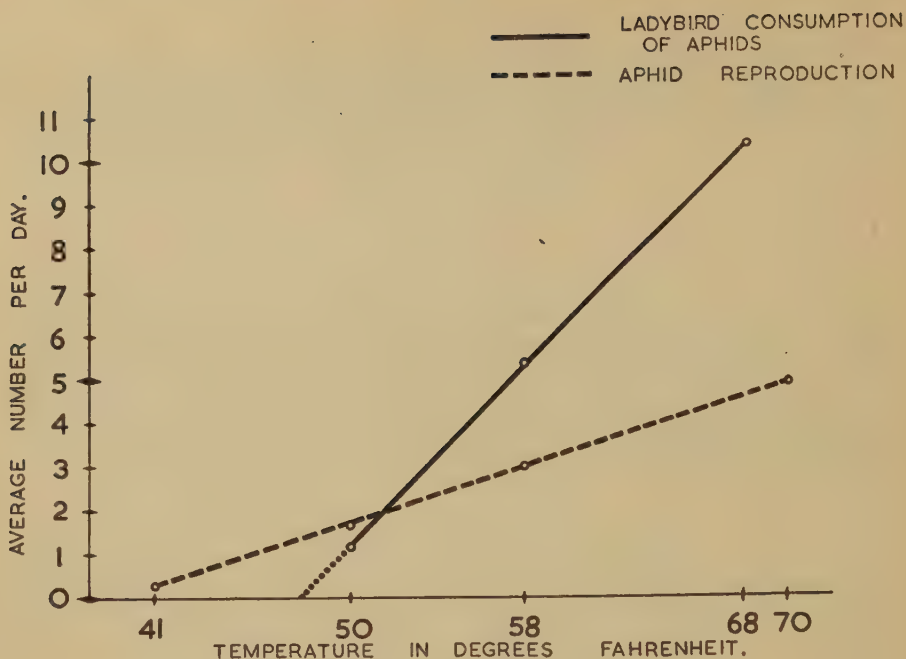


Fig. 1

The average number of aphids consumed and produced each day at various temperatures.

Results

The graph, Fig. 1, shows the average daily number of aphids consumed per ladybird at different temperatures, together with the equivalent reproduction figures per pea aphid aptera. This shows that aphid reproduction occurred at a very low rate at 41°F., and that, over the temperature range used, it increased progressively to give an apparently straight line relationship.

In the case of the ladybird, no activity occurred at 41°F. Feeding began several degrees above this point and increased at a much greater rate, as the temperature rose, than did the reproductive activity of the aphid. The numbers of aphids consumed by the predator and produced by the host were equal at approximately 51°F. Over 52°F., the two curves diverged from each other, that for the ladybird showing the steeper rise.

DISCUSSION

At temperatures below 51°F., the pea aphid can build up populations at a greater speed than can be checked by the ladybird. When the temperature exceeds 52°F., the ladybird is potentially capable of reducing the aphid population. This differential effect of temperature on host and predator is undoubtedly a factor influencing the seasonal abundance of the aphid on perennial legumes. In March and April, and again in late September and October, pea aphid populations in the field increase markedly. The average temperature over these periods is often below 50°F., which must enable the host to multiply with little interference from the predator.

In summer, the higher average temperature favours the predator and gives it an advantage over the host. Sudden cold periods during summer, however, operate against the ladybird in that they reduce this advantage, since the temperature approaches to a greater or lesser extent, the critical point of 'consumption-reproduction' equilibrium.

SUMMARY

1. The reproduction rate of the pea aphid (*Acyrtosiphon pisum* Harris) and the feeding rate of the adult seven spot ladybird (*Coccinella septempunctata* Linn.) have been studied at four temperatures between 41°F. and 70°F.

2. At 41°F. the aphids reproduced slowly but the ladybirds were inactive and did no feeding.

3. Between 41°F. and about 51°F., each *A. pisum* aptera gave birth to a greater number of progeny than the number of aphids which a single *C. septempunctata* could consume.

4. Above 52°F., the consumption potential of the ladybird exceeded, in increasing measure, the reproduction potential of the aphid.

5. These findings indicate that in the field, low spring and autumn temperatures help the aphid populations to build up by limiting ladybird activity, whereas warm summer weather can help to control the aphid by increasing the efficiency of the ladybird as a predator.

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NOTES ON INSECTICIDAL DUST DEPOSITS WITH SPECIAL REFERENCE TO THE PEA APHID

(*Acyrtosiphon pisum* Harris)

By G. A. WHEATLEY

INTRODUCTION

One of the fundamental problems of insecticidal dusting of crop plants is that of getting an adequate deposit of dust from the dust cloud. A dust may have an excellent inherent toxicity to an insect, as shown by laboratory tests, and yet prove relatively ineffective for field use because its physical nature does not allow good deposition from the dust cloud onto the crop harbouring the pest. It has been pointed out by Potts (1) that failure to obtain good control in the field is often due to relatively light deposits and poor adherence rather than to the small quantity applied or to the small number of particles involved.

A lethal dose of contact poison may be collected by the insect in two main ways as a result of dusting. The contact may be established by the insect's moving over the dusted surface, or the dust may be deposited on the insect's body during the dusting operation. The degree of control is usually the resultant of these two actions and, hence, may be determined largely by the habits of the insect; some species remain more or less concealed in small niches on the plant whilst others wander extensively. Temperature is another factor to be considered since it has an important influence on the general activity of all insects.

It is difficult to obtain deposits of dusts within the growing points and flower heads where aphids are often found and this may affect control since the pest may escape direct treatment. Compared with other aphids, the pea aphid (*Acyrtosiphon pisum* Harris) is relatively active, especially at temperatures greater than about 65°F., so that the necessity for dusting the actual aphids will be much reduced if, stimulated by suitable temperatures, they can acquire a lethal dose during their 'routine' wanderings over the dusted plant surface.

The necessity of bringing the dust into direct contact with the insect has been explored for the pea aphid by a laboratory experiment aimed at assessing the relative degrees of toxicity produced, firstly, by dust landing upon the insect's body and, secondly, by dust picked up from the plant surface as the insect moves.

EXPERIMENT TO DETERMINE THE RELATIVE DEGREES OF TOXICITY PRODUCED BY (a) DUST UPON THE BODY OF THE INSECT AND (b) DUST UPON THE SURFACE OVER WHICH THE INSECT MOVES

A brief description of the laboratory bio-assay technique is given below and it is hoped to publish this elsewhere in greater detail.

Rearing of insects and plants

The rearing techniques employed for the plants and aphids were similar to those described by Deitter *et al.* (2). The variety of peas used throughout the work was 'Onward' and all aphids used were of a pure line stock originally derived from a single agamic female. Only fourth instar apterae were used for the test. They were transferred from the breeding plants and bulked in a common 'pool' before being placed upon the specially prepared plants used for the treatments. These latter plants were matched carefully for size and conformation, and the lower leaves and growing-points were excised in order to minimise cover for the aphids and unevenness of deposit.

The laboratory dusting apparatus

The machine used for the production of known deposits in the laboratory consisted of a dusting unit which directed an horizontal dust stream past a plant revolving slowly on a turntable. A constant feed mechanism ensured even delivery of dust for quantities within the range 0.1 to 5.0 gm. The whole assembly was situated in a form of wind tunnel from which the surplus dust was ejected by means of an exhaust fan.

Treatments

A $\frac{1}{2}$ per cent. DDT/Talc formulation which had been prepared a fortnight previously by ball-milling for four hours was used throughout the following treatments :—

- (a) 0.5 gm. ; a standard treatment in which the aphids and plants were dusted and remained in association together.
- (b) 0.5 gm. ; aphids removed to undusted plants immediately after treatment, i.e., aphids dusted, plants not dusted.
- (c) 0.5 gm. ; dust applied to plants before the transference of clean aphids, i.e., aphids not dusted, plants dusted.
- (d) 1.0 gm. ; as for (a) above.
- (e) 1.0 gm. ; as for (b) above.
- (f) 1.0 gm. ; as for (c) above.
- (g) Undusted control.

Method

Approximately 3-4 hours before the treatments were applied, 15 aphids were counted from the common "pool" onto each plant scheduled for dusting. The method of confining the aphids to the plants for the duration of the test has been described elsewhere (3) and consists of an arrangement of electrical barriers which obviate the need for cages with their consequent microclimates. Five hours prior to and throughout the test, the plants and insects were kept in a controlled environment room ($74 \pm 1^\circ\text{F}$. ; $60 \pm 3\%$ relative humidity) and were only removed to a separate dusting room for the treatments to be applied. The post-treatment transferences were all carried out immediately after dusting the particular plant. Five plants were used for each treatment so that the mortality percentages were each based on a total of 75 aphids.

Counts were made 24 hours after treatment, when the aphids were classified into the categories 'alive,' 'slightly affected,' 'badly affected,' and 'dead.' In calculating the percentage mortalities, the two former categories were considered as the living and the two latter as the dead.

Results

The results for the respective treatments are presented in Table I as the simple percentage mortalities after allowance has been made by Abbott's correction (4) for 8.11 per cent. deaths in the controls. The summation of the mortalities for treatments (b) and (c), and (e) and (f) are shown also for comparison with (a) and (d) respectively.

TABLE I

The effect of placement of DDT dust on the toxicity
to the pea aphid

Treatment	% Mortality
(a) 0.5 gm. ; standard, plants and aphids dusted	72.98
(b) 0.5 gm. ; aphids dusted, plants not dusted	13.26
(c) 0.5 gm. ; aphids not dusted, plants dusted	59.91
(d) 1.0 gm. ; standard, plants and aphids dusted	84.22
(e) 1.0 gm. ; aphids dusted, plants not dusted	26.12
(f) 1.0 gm. ; aphids not dusted, plants dusted	59.37
(g) Control, undusted	8.11

Discussion

It is clear from the above results that, under the conditions of the experiment, the major portion of the toxicity of the dust deposit could be attributed to that picked up by the insect during the course of its movements over the plant. The dust actually deposited on the insect's body did not have such a great effect. Thus it seems that entry of the toxicant into the insect is mainly via those parts which are in intimate and constant contact with the dusted surface, namely the tarsi, ventral surface of the abdomen and possibly the antennae. This may result from either a larger quantity of dust being collected at these points during movement or from the fact that the cuticle of these parts of the body is subjected to constant abrasion due to contact with the substratum, thus allowing the insecticide to enter more easily. It is of interest that the summations of these two main actions, as indicated in Table I, are in very close agreement with the results of the respective standard treatments.

Dusts containing various methylnaphthalenes have been reported by Sun and Hansberry (5) to show a behaviour against the pea aphid similar to the above, but they found that the action of rotenone dusts was only slightly affected by placement of the insecticide. They concluded that the vital site of action of the former dust is probably located in the tarsi, whilst the rotenone may act via the whole body surface. Thus, it would appear that the effect of placement of the dust depends on the type of insecticide used.

The degree of control of pea aphids with DDT dusts apparently depends, to a large extent, on that dust which is picked up by the insect as a result of movement. This indicates that field dusting operations should be carried out only when the prevailing temperature is above about 65°F. so that full use can be made of the insect's movements to obtain satisfactory control.

THE INFLUENCE OF LEAF AND STIPULE SIZE OF THE PEA PLANT ON THE DEGREE OF DEPOSIT FROM THE DUST CLOUD

The extent to which the factors determining the *degree* of deposit obtained from a dust cloud operate is still largely unknown but the effect of one such factor, namely, the leaf size of the crop, was shown by the following experiment with pea plants. A bio-assay technique similar to that above was used to follow up the variations in deposit obtained by dusting plants of differing leaf and stipule sizes.

Controlled growth of pea plants

Plants of variety 'Onward' were grown singly in five-inch diameter pots. All the plants were treated alike until they were some two inches in height whereupon they were selected for uniformity and their subsequent leaf and stipule development was regulated into one of three groups by means of differential watering.

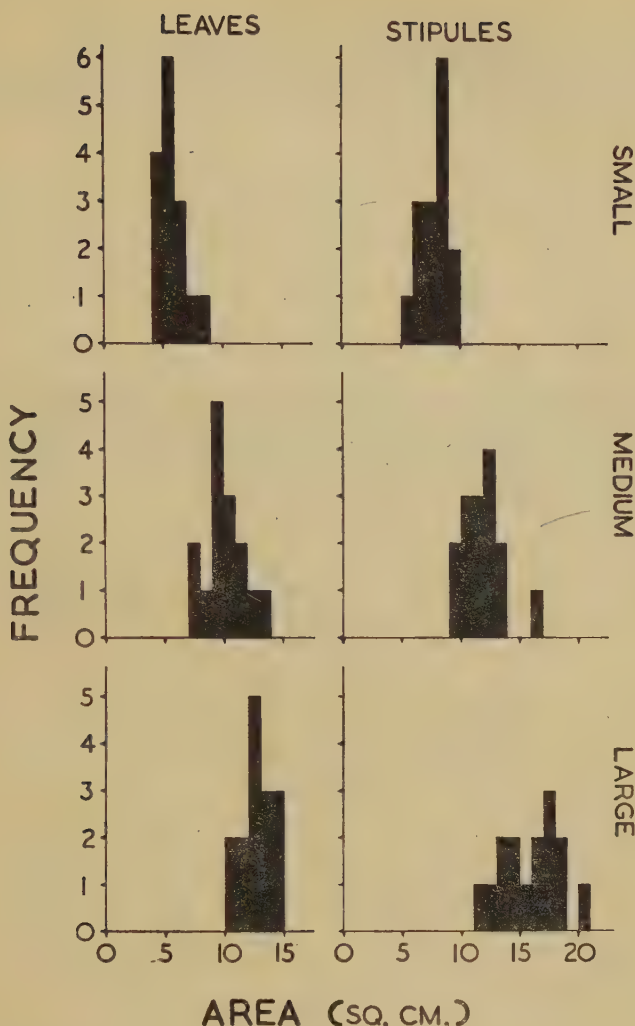


Fig. 1

Distribution of the mean leaf and stipule sizes per plant for the fifteen plants of each group.

The plants which were to comprise the large and medium sized groups received one gallon and one-half gallon of water respectively per 30 plants every 2-3 days, whilst those to represent the small leaf-sized group received one-half gallon of water per 30 plants every 4-5 days. After reaching the fifth node, they were again selected for uniformity before being clipped and trimmed to be all of similar overall spread and height. At this stage measurements were made to the nearest 0.25 cm. of the diameter of the individual leaves (treated as circles) and of the length and breadth of each pair of stipules (treated as rectangles). The distributions of the mean sizes of leaves and stipules per plant for each group are shown diagrammatically in Fig. 1. Whilst there was some overlap at the extremes of each size range, the plants, as a whole, showed a sufficient difference in leaf and stipule size between groups to have revealed any serious effect of size on the deposit of dust.

Treatments and layout of the experiment

A series of five treatments was replicated three times for each size group of plants using the same dust as in the previous experiment. These treatments were as follows :—

- (a) 0.10 gm.
- (b) 0.14 gm.
- (c) 0.20 gm.
- (d) 0.30 gm.
- (e) Undusted control.

There were 20 aphids per plant and counts of mortalities were made 24 hours after treatment. The plants and aphids were kept in a controlled environment room ($75 \pm 1^\circ\text{F}$. ; $50 \pm 3\%$ relative humidity) for four hours before, and throughout the course of the experiment.

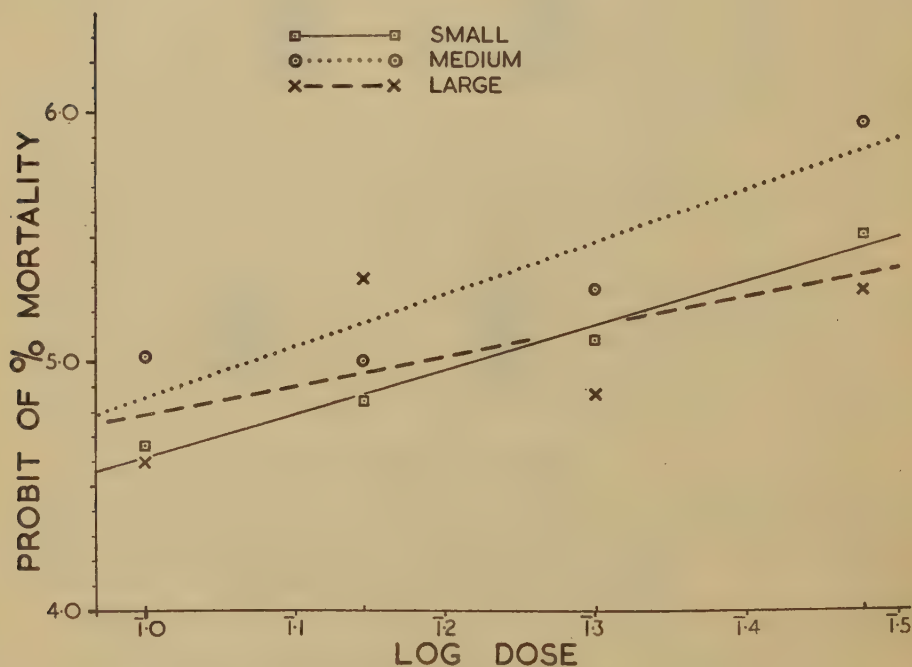


Fig. 2

Regression of the probit of the percentage mortality against log dose.

Results

The aphids were divided into the same categories as described in the previous experiment and the percentage mortalities, duly corrected for natural deaths among the untreated controls, are presented in Table II ; the derived probit curves are given in Fig. 2 and a statistical analysis showed no detectable heterogeneity between either slopes or means of the curves.

TABLE II
Percentage mortalities produced by the treatments

Plant group	Treatments (gm. dust)				
	0.10	0.14	0.20	0.30	Control
Large	34.46	62.94	44.57	61.11	4.26
Medium	50.84	50.13	61.25	82.75	1.72
Small	36.81	43.83	53.18	69.23	5.09

These results show, by reason of the similar mortality trend, that for all practical purposes, the deposits on the three groups of plants were the same and confirmation of this was obtained by counting the number of particles per $\frac{1}{4}$ sq. mm. of upper leaf surface for two plants of each group which received 0.10 gm. dust. Such a count is difficult owing to the presence on the leaves of foreign matter (particles of soil, atmospheric dust, etc.) some of which cannot be readily distinguished from the particles of insecticidal dust. The figures are given in Table III and, indeed, do show that any difference in deposit was almost negligible.

TABLE III
Average number of dust particles per $\frac{1}{4}$ sq. mm.
upper leaf surface for a dose of 0.10 gm. ;
mean of 20 counts

Plant group ..	Large	Medium	Small
Nos. of particles ..	5.9	4.3	4.4

Discussion

Recent investigations by Gregory (6) have shown that one of the factors governing the efficiency with which a simple target traps air-borne particles directed at it, is the size of the target itself. His results show that the efficiency of cylinders as traps for *Lycopodium* spores is affected by, among other things, the diameter of the cylinder ; for instance, an increase in cylinder diameter from 0.2 to 2.0 cm. decreases the efficiency of trapping of *Lycopodium* spores carried in an air-stream from approximately 46.0 to 0.2 per cent. with an air velocity of 1.1 m./sec., and from 71.0 to 27.0 per cent. with an air velocity of 9.7 m./sec. Aero-dynamic principles indicate that the same phenomenon should hold for flat surfaces, though to a different degree. The writer has observed that the deposit per unit area from a given dust cloud was four times greater on $\frac{7}{8}$ inch diameter circular glass coverslips than on $3\frac{1}{2} \times 2\frac{1}{2}$ inch rectangular glass slides.

However, these observations relate only to the properties of single, detached surfaces, whereas a plant may be considered as really a group of such surfaces (leaves, stipules, stems, etc.) and is thus a compound target in which the surfaces will tend to show mutual interference with each other by creating unknown degrees of turbulence in the dust stream with consequential influences on deposit.

The concept of multiple surfaces forming a compound target is only one of degree, depending upon the relative distances separating the respective areas. In the limit, if these surfaces are sufficiently widely separated, they will show no mutual interference ; if they are brought close together their effective behaviour will be that of a single large area.

The results of the above experiment indicate that, in the case of the pea plant, the surfaces provided by the individual leaves are so close together that it is the overall size of the plant which is the important feature. The operative factor determining the main turbulence around the plant structure then becomes the interference drag effect of the whole plant on the air-stream (not to be confused with skin friction of air flowing over the surface of the plant). Thus the potential individual effects of leaf and stipule size of pea plants are overshadowed by the overall dimensions of the plants as determinants for the degree of deposition from a dust cloud.

It seems reasonable to assume, on the basis of the above discussion, that the degree of deposition produced by a duster under constant conditions will depend upon the conformation of the crop being treated. The extent to which this factor will operate cannot be predicted without more detailed studies, but it might be expected, for example, that, to obtain equal deposits, potatoes would approach more nearly to peas than to cabbages or Brussels sprouts in treatment requirements.

SUMMARY

1. Experimental results indicate that, for pea aphids, the main contribution to the toxicity of DDT dusts is from toxicant picked up from the dusted surface of the plant, rather than from dust deposited on the insect's body during the dusting operation. Thus the influence of temperature on the activity of the pea aphid will affect the degree of control obtained by dusting.

2. It is shown that the degree to which dust deposits from a dust cloud onto a pea plant is independent of variations in the size of individual leaves or stipules. The overall form of the whole plant structure probably masks the effects of individual parts of the plant in this respect.

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THE EFFECTS OF CERTAIN ADVERSE CONDITIONS ON GROWTH AND LATE DEVELOPMENT OF CAULIFLOWER AND LETTUCE

By E. J. WINTER

1. THE INFLUENCE OF POT SIZE ON GROWTH AND DEVELOPMENT OF CAULIFLOWER (VAR. MAGNIFICENT) IN SAND CULTURE

Using Hewitt's sand culture technique (1), cauliflower seedlings at the five-leaf stage were planted in 4, 6, 10, 12 and 20-inch bitumen-lined pots containing 1, 2, 10, 20 and 100 kg. of sand, respectively. A waxed cardboard collar, four inches in diameter and four inches high, was placed round each young plant to eliminate possible differential effects of reflection from the white sand and radiation from the black pot walls. The pots were grouped in an unheated greenhouse so that the space available for aerial growth was approximately proportional to pot diameter. Whenever the top two inches of sand in any pot had lost coherence, all the pots were watered with excess of a full nutrient solution suggested by Dr. E. J. Hewitt. The pots were leached with tap water once each week. Establishment of the plants was easy, except in the 20-inch pots where the culture solution drained very quickly from the upper layers of sand. Thus, at first, the plants in 20-inch pots grew more slowly than those in smaller pots, until their roots had tapped the moist lower layers of sand.

Results

Figures 1A and 1B show typical data obtained for growth of various parts of the plants. Once all the plants were established, the larger the pot, the faster and bigger the plants grew. The rate of growth and final size were more nearly proportional to pot diameter than to volume of culture medium. This suggests the possibility that under these conditions of abundant nutrient supply, growth was influenced more by the distance apart of the plants, and therefore by the amount of light falling on them, than by the space available for their roots.

Maximum vegetative size was attained earlier with the smaller pots than with the larger ones (Fig. 1A), probably because under conditions of plentiful nutrient supply, size of the aerial parts of the plants was limited by available space and light.

The first signs of curding were visible in late June, more or less simultaneously in the 10, 12 and 20-inch pots. The plants in 6-inch pots began to curd in late July, while those in 4-inch pots did not reach this stage until after September. Variation in curding date was greatest among the plants in 4-inch pots, and the last one did not curd until December.

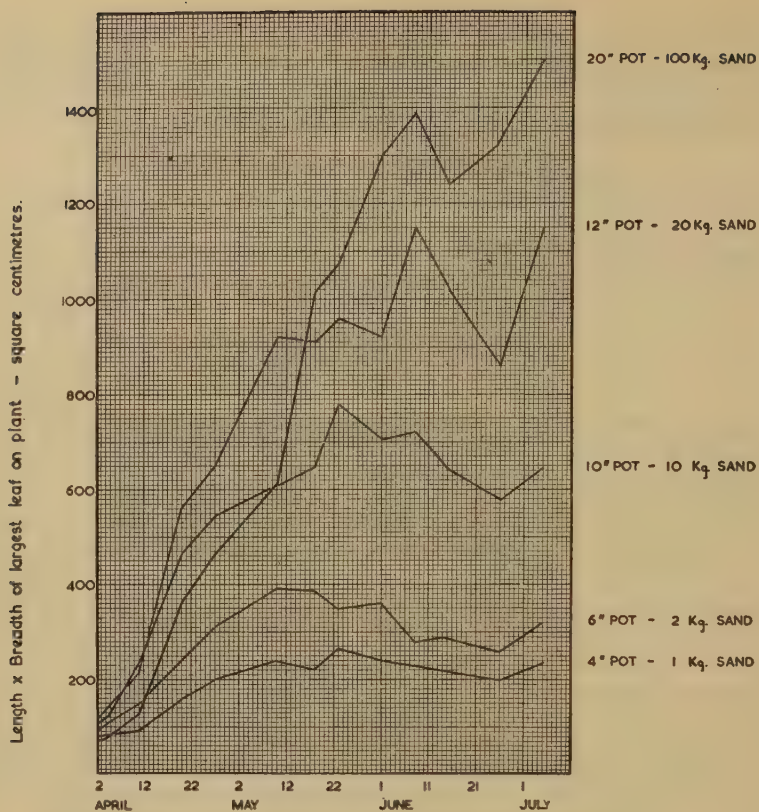


FIG. 1A Mean leaf size of cauliflower plants in sand culture (full nutrient solution), in pots of various diameters.

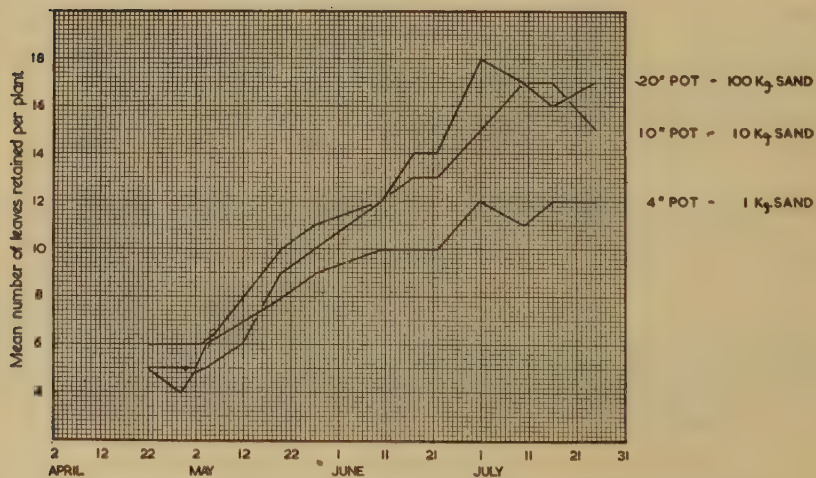


FIG. 1B Mean number of unfolded leaves retained on cauliflower plants in sand culture (full nutrient solution), in pots of various diameters. As in Fig 1A, the curves for 12" pots and 6" pots lie between those for 20" and 10", and 10" and 4" respectively, but have been omitted for the sake of clarity.

Curding of the cauliflower, under the conditions of this experiment, was apparently neither dependent on day-length, temperature or other external factor, nor on the attainment of a certain size of plant. A possible explanation was that although some very early stage in the development of the flowers may have depended on one or more of these factors, the speed of attainment of the curded stage was thereafter dependent on growth rate, which was found to be associated with the space available for root and shoot growth (Fig. 1A).

As mentioned previously, the intake of nutrients by the plants in the very large pots was mechanically hindered in the early stages. Delay in imbibing the assumed threshold quantity of nutrients for some pre-curd stage in flower initiation could have been counteracted by the greatly increased rate of growth at later stages. This would explain why the plants in 20-inch and 12-inch pots did not flower before those in 10-inch pots.

The sizes of the bolted plants varied according to the size of pot. As with curding, a certain threshold size of plant did not appear to be necessary before bolting could occur.

2. THE EFFECT OF SPACING AND TRANSPLANTING ON HEARTING AND BOLTING OF LETTUCE (VAR. WHITE BOSTON) IN THE FIELD

This experiment was laid down on an area which had carried sugar beet the previous season. No manure was added, but the beet tops were ploughed in.

Spacing treatments

Three spacing treatments were used, namely, six inches, twelve inches and eighteen inches square. Each plot consisted of four rows, each of 22 plants. The two outer rows, and the end plants of the inner rows, comprised the guard rows. Thus there were 40 plants in every plot, exclusive of guard rows, and the plot areas differed in the different spacing treatments.

Transplanting treatments

The three spacings were combined factorially with the following three degrees of severity of planting-out treatment :—

Not transplanted. On 11th May, seed was drilled in rows. On 25th June, the seedlings were thinned to the required spacing.

Once transplanted. On 25th June, four-leaved seedlings from the non-transplanted plots were planted out at the appropriate spacings.

Twice transplanted. As for 'once transplanted,' but on 13th July all the plants were again dug up and replanted.

In all transplantings, care was taken to keep the severity of damage as uniform as possible. The same pair of operators dug up every plant by loosening the soil with a trowel and then pulling out the plant. The pulled plants were placed in trays from which they were taken, without selection, by a team of four planters. Each planter planted one quarter of every plot, using a dibber.

Results

Each plant was scored as having hearted, as soon as its central leaves began to fold inwards, i.e., it was not necessarily 'hearted' in the commercial sense. Each plant was recorded as having bolted, as soon as the flowering shoot broke through the top of the heart. It was thus possible to compute for each plot the 'fifty-per-cent. hearting time' (number of days from sowing until half of the plants had hearted) and the 'fifty-per-cent. bolting time' (number of days from sowing until half of the plants had bolted).

The results are summarised in Tables I and II and are shown graphically in Figs. 2A and 2B.

TABLE I
Days from sowing until 50% of lettuce plants had hearted

	Spacings			Mean
	6-inch	12-inch	18-inch	
Not transplanted	87.7	76.2	76.0	80.0
Once transplanted	119.0	102.6	96.7	106.1
Twice transplanted	106.1	104.2	104.0	104.8
Mean	102.3	94.3	92.2	96.3

Least significant difference for :	P=0.05	P=0.01
Between treatment means ...	8.41	11.4
Between transplanting means or between spacing means ...	4.85	6.58

TABLE II
Days from sowing until 50% of lettuce plants had bolted

	Spacings			Mean
	6-inch	12-inch	18-inch	
Not transplanted	100.2	91.8	90.5	94.2
Once transplanted	124.3*	114.5	109.0	115.9
Twice transplanted	117.5	116.7	115.8	116.7
Mean	114.0	107.7	105.1	108.9

*This entry includes a calculated missing plot value.

Least significant difference for :	P=0.05	P=0.01
Between treatment means, neither containing the missing plot	6.01	8.15
Between treatment means, one containing the missing plot	6.55	8.88
Between transplanting means, or between spacing means, not containing the missing plot	3.47	4.71
Between transplanting means, or between spacing means, containing the missing plot	3.54	4.80

It will be seen that hearting and bolting were delayed by close spacing and by transplanting. The closer the spacing, the greater was the delay. In general, the delaying effect of transplanting twice was not significantly greater than that of transplanting once. At six-inch spacing, plants which had been once transplanted gave an apparently anomalous result. Quantitatively, the delaying effect of transplanting was greater than that of close spacing.

LEAST SIG. DIFF ($P=05$)

= 8.4 DAYS



DAYS
FROM
SOWING

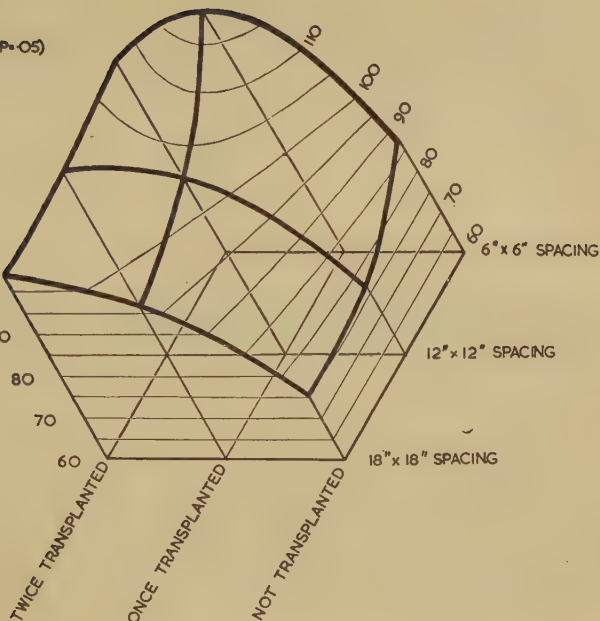


FIG. 2A Mean 50% Hearting Time for lettuce at three spacings and three transplanting treatments.

LEAST SIG. DIFF
($P=05$) FOR COMPARISONS
INCLUDING THE MISSING
PLOT = 6.55 DAYS



DAYS
FROM
SOWING

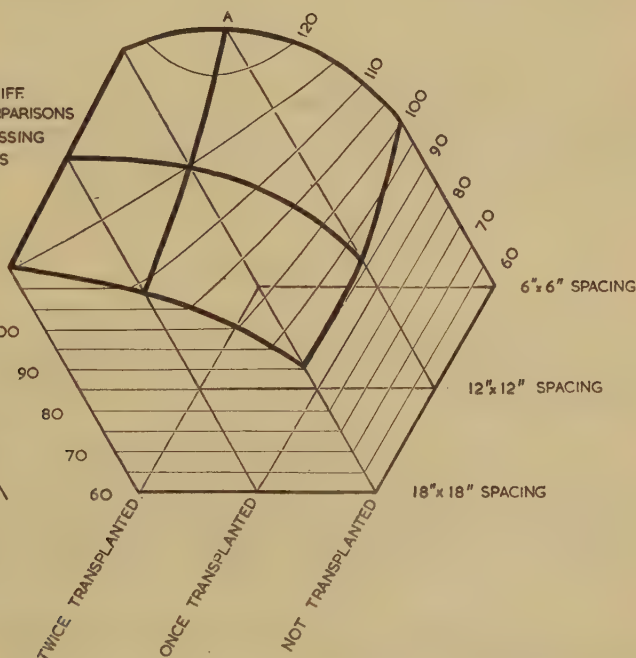


FIG. 2B Mean 50% Bolting Time for lettuce at three spacings and three transplanting treatments. Point A includes a calculated missing plot value.

The plants were not scored for marketability, but it was noticeable that all the non-transplanted plants at twelve- and eighteen-inch spacings produced good hearts. On the other hand, many of the once transplanted plants at these spacings failed to produce hearts of marketable size, while only a very few of the twice transplanted plants formed good hearts. No plants at six-inch spacing produced marketable lettuce either with or without transplanting.

DISCUSSION

In these experiments, the late stages of flowering and bolting were delayed, by close confinement of both roots and shoots in the case of cauliflower in sand culture, and by close spacing and mechanical damage in the case of lettuce in the field.

Landau (2) found that the inside rows of experimental onion beds contained fewer bolters than did the outside rows. Warne (3) reported fewer bolters at close spacing in carrot, beet and shallots. Whyte (4) stated that seed-stalk formation in celery is checked by crowding, soil drought or other adverse conditions. In an earlier experiment the author (5) found that sand cultures of lettuce at high levels of nitrogen and potassium nutrition were at all times ahead of those at lower levels, in size, stage of development and quantity of flowers.

It seems evident that reduction in growth rate due to a variety of environmental causes can delay flowering under certain conditions. Nevertheless, in the present experiments, flowering was not shown to depend on the attainment of a certain minimal size, because plants which were much smaller than normal plants by reason of confinement, close spacing, or transplanting, did eventually produce flowers.

The postponement of flowering by reduction in growth rate is all the more interesting in view of the classical fundamental distinction between growth and development. Suitable adjustment of the environment may be expected to accelerate flowering, an effect which would be most useful to those interested in the production of seed in this country.

SUMMARY

1. Cauliflowers were grown in sand culture in five different pot sizes. Growth rate and final size increased with increasing pot size. Plants in the three largest pot sizes curded at the same time, followed by the others in decreasing order of pot size.
2. Lettuce was grown in the field at three spacing treatments combined with three degrees of severity of transplanting treatment. Hearting and bolting were delayed in the order of closeness of spacing and severity of transplanting treatment. Transplanting reduced the number of lettuce which reached marketable size; no marketable lettuce were produced at six-inch spacing in any transplanting treatment.
3. Neither in cauliflower nor in lettuce did flowering depend on the attainment of a certain minimum size of plant.
4. It is suggested that reduction in growth rate by various agencies can delay the later stages of development and flowering, irrespective of the size of the plant.

The author wishes to thank Professor T. Wallace, for kindly providing facilities for carrying out the cauliflower experiment at Long Ashton, and Dr. E. J. Hewitt for advice and generous help in connection with the sand culture technique.

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EXPERIMENTS ON VEGETATIVE AND REPRODUCTIVE GROWTH OF CAULIFLOWER

By A. H. PARKINSON

INTRODUCTION

Late maturing varieties of cauliflower are normally marketed during October and November. Seed production of these varieties in this country is difficult as the plants do not survive the winter and protection of large numbers of mature plants under glass would be expensive. Although a good yield of seed might be obtained by sowing out of season and protecting the young plants under glass, there is the possibility that seed thus obtained, from plants which cannot be selected for performance under normal conditions, would give rise to inferior plants. Late varieties, therefore, are chiefly grown for seed production in milder climates.

Experiments were planned to investigate the possibility of developing a practicable method for home seed production of late cauliflower. A successful method, even though uneconomic for commercial seed production, would be of great value to the plant breeder. Similarly it would be a useful service to the plant breeder if a technique could be devised to maintain plants in a vegetative condition until flowering was desired. In the following experiments, therefore, a study was made of the influence of several factors on vegetative and reproductive growth.

MATERIALS AND METHODS (GENERAL)

Three varieties were used in the experiments, Pioneer (early), All-the-Year-Round (mid-season and general), and Novo (late). Seeds were sown, unless otherwise stated, in boxes containing John Innes potting compost No. 1 (J.I.P.1) and the seedlings were pricked out into John Innes potting compost No. 3 (J.I.P.3) in boxes or 2½-inch pots.

One experiment was carried out at the Royal Botanic Gardens, Kew, and the others at Chelsea Physic Garden. The open ground, where plants were set out in their final positions, was prepared during spring by applying farmyard manure or spent mushroom compost at about 30 tons per acre, hydrated lime at 4 oz. per sq. yd., and mixed base fertiliser at 6 oz. per sq. yd.

Counts of all leaves over 2 cm. in length, including those which had been shed, were made at various times during the season as a measure of the rate of vegetative development. Final leaf number was taken as the total number of leaves produced up to and including the first leaf with curd in its axil. Cutting date (or date of curd maturity) was taken to be the time when a head was ready for marketing. In many instances the heads were not removed from the plants but cutting date was noted since it was a stage in progress to flowering and seed production. In some experiments the date when the first flower opened was recorded and observations were made on the production of ripe (brown) seed.

RESULTS

Photoperiodism

A. Preliminary day-length treatments followed by natural day conditions

In this experiment, all three varieties were sown on each of four dates, each of which was appropriate to one or more of the three varieties used. The sowing dates and the timing of these in relation to general practice for each variety are shown in Table 1. (The results from the last sowing date, 10th October, were not available at the time of writing and so cannot be discussed here. Results from this sowing date

may show whether ripe seed of Novo can be obtained before the frosts, by sowing late in the previous year and protecting the plants under glass in their young stages only. Plants from this sowing will all be grown in natural day-length.)

TABLE I

Sowing Dates

Variety	5th February Heated glasshouse	31st March Slightly heated frames	24th April Out-of-doors	10th October Dutch lights
Pioneer	Suitable	Late	Very late	Suitable
All-the-Year-Round	Suitable	Suitable	Late	Suitable
Novo	Very early	Early	Suitable	Very late or Very early

Plants from the 5th February sowing were raised in pots in a glasshouse (60-65°F. day and 50-55°F. night) and, after hardening off, were planted out on 12th April. Plants from the 31st March sowing were raised in boxes in slightly heated frames and were planted in the field on 31st May. Plants from the third sowing date (24th April) were raised in the open, on land prepared for growing cauliflower plants to maturity, and were planted in the field during the third week of June.

Some plants of each variety from the first three sowing dates were grown in long days (17 hours) and others in short days (8 hours). Long days were obtained by the use of supplementary illumination of low intensity and short days were obtained by covering with light-tight boxes. Day-length treatments were started before germination and were terminated seven weeks after seedling emergence ; hence these were termed 'preliminary day-length treatments.' The plants were then grown in natural days. Control plants were grown in natural days throughout.

There was thus a total of 27 treatments and the plants were set out at 2 ft. sq. in the field at the Royal Botanic Gardens, Kew. Records were taken of cutting date, date of the first open flower, and time of production of ripe (brown) seeds. Some plants from each of the first two sowing dates died before field planting and this reduced the accuracy of the results. Reasonably good comparisons of treatments could be made, however, with All-the-Year-Round, and the results for curd maturity are shown in Table II.

TABLE II
Mean days from sowing to cutting date of All-the-Year-Round

Preliminary day-length treatment	Sowing date			
	5th February	31st March	24th April	Mean
Long day (17 hours)	155.0	129.8	119.6	134.8
Short day (8 hours)	160.8	131.6	130.6	141.0
Natural day	162.0	129.0	118.5	136.5
Mean	159.3	130.1	122.9	137.4

Least significant difference between :					P=0.05	P=0.01
Individual treatment means	...	...	...	...	3.6	5.0
Sowing date means	}	...	...	...	2.1	2.9
Day-length means						

With plants from each sowing date, there were no major effects of any preliminary day-length treatment on the number of days from sowing to cutting date. The difference, although sometimes reaching significance, was probably attributable to differences in temperature and total energy received during the day-length treatments. Since preliminary photoperiod treatment appeared to be of little importance, the marked reduction in time to cutting date associated with later sowing was probably a result of generally better growing conditions and greater total radiation received, i.e., longer days and increased sunshine, subsequent to preliminary treatments.

With Pioneer and Novo there were but few plants in certain treatments owing to deaths before field planting. The results, however, confirmed those shown in Table II, and with plants from each sowing date, the general order of head maturity was Pioneer, All-the-Year-Round, Novo, except at the second sowing date where there was no detectable difference between Pioneer and All-the-Year-Round.

There was a much greater range in the time of head maturity of Novo as sowing date was advanced. Plants sown early, matured from late July to late October; from the second sowing date, heads matured from early September to early November, and from the third sowing date, heads were ready for cutting from the end of September to early November. Nearly all the heads of Pioneer and All-the-Year-Round from each sowing date were marketable. Novo heads that matured after late August were marketable but the majority of those produced before this time were 'ricey'.

As far as could be determined, there was no after effect of the preliminary day-length treatments on time between head maturity and production of the first open flower of Pioneer and All-the-Year-Round. Novo plants from the second and third sowing dates did not flower before the frosts. Late in the season, the rows of plants from the first sowing date presented a mixed appearance; some plants bore immature seed pods, others were flowering, and others had unextended bracteate heads. Ripe seed was produced only by Pioneer from the first sowing date which was given a preliminary treatment of long days, but plants from other treatments with this sowing date produced large green seeds before the occurrence of frosts.

B. Day-length treatments throughout the season

Plants of Pioneer from the 5th February sowing, All-the-Year-Round from the 31st March sowing, and Novo from the 24th April sowing (their appropriate sowing dates), were grown throughout the season in long days (17 hours), short days (8 hours), or natural days. Thus each variety was grown at a time when it would normally crop successfully but those in long days were subjected to a day-length approximating to that of the longest day of the year, and those in short days received a day-length near to that of the shortest day.

The results for head maturity are shown in Table III.

TABLE III
Mean days from sowing to cutting date

Treatment	Pioneer	All-the-Year-Round	Novo
1. Long day ..	144.0	123.8	176.3
2. Short day ..	153.1	135.9	207.2
3. Natural day	156.8	126.9	180.1

Least significant
difference between :

P=0.05		P=0.01	P=0.05		P=0.01	P=0.05		P=0.01
1 and 2	} 4.8	6.5	1 and 2	} 5.8	7.9	1 and 2	25.2	37.3
1 and 3			1 and 3			1 and 3	10.9	15.3
2 and 3			2 and 3			2 and 3	25.0	37.0

With Pioneer, there was no significant difference in cutting date between short and natural day plants but those grown in long days were earlier. With All-the-Year-Round and Novo, there was little difference in cutting date between plants in natural and long days but the plants of both varieties matured later under short day conditions. Again, as with preliminary day-length treatments, it appeared that there was perhaps no true photoperiodic effect and that the differences could probably be accounted for on other grounds (temperature, total radiation received, and the necessity of growing the long day plants in a plot at some distance from those in natural days).

Methods of plant raising and the influence of checks given to young plants

Seeds of All-the-Year-Round were sown on 31st March and placed in a slightly heated frame. When the first foliage leaf was expanding, some seedlings were pricked out into pots or boxes and others were left undisturbed in the original box.

Five treatments were included in the experiment: pot-grown, pot-grown with drought check, box-grown, box-grown with planting check, and unpricked-off. The drought check was started when the seventh leaf was expanding. The plants were not watered until all but the youngest, partly expanded leaves were drooping, and water was not supplied again until they were once more severely wilted. This treatment was concluded after 16 days, when the potting compost was thoroughly soaked with water. The plants were then set out (80 days after sowing) in plots, together with those from the remaining treatments. The planting check treatment consisted of trimming the roots of box-grown plants to one-inch long at the time of setting out the plants. Unpricked-off plants were grown in J.I.P.1 until planting out date but seedlings of other treatments were potted in J.I.P.3 or were pricked-out in boxes of J.I.P.3.

Leaf numbers (leaves over 2 cm. long) at planting out date, and final leaf numbers, are shown in Table IV.

TABLE IV
Mean leaf numbers

Treatment	80 days after sowing (planting out date)	Final leaf number
1. Pot-grown	10.4	43.5
2. Pot-grown with drought check	8.8	41.8
3. Box-grown	10.5	42.8
4. Box-grown with planting check	10.3	42.2
5. Unpricked-off	8.9	41.9

Least significant difference :	P=0.05	P=0.01	P=0.05	P=0.01
1-4 between themselves ...	0.9	1.3	5.7	9.5
1-4 with 5	1.3	2.0	5.7	9.5

At planting out date, the mean leaf numbers of drought-checked and unpricked-off plants were significantly lower than those of the remaining treatments, but some unpricked-off individuals had a leaf number as great as that of any plant in the experiment. At this time, the variability in leaf number of the unpricked-off plants was somewhat greater ($P=0.1$) than that of the plants in the remaining treatments. It must be borne in mind that at pricking out time, plants of approximately uniform size were selected, but with unpricked-off plants, however, those arising from late germinating seeds may have been included in those planted out.

There were no significant treatment differences in final leaf number and there was no detectable heterogeneity of variance between treatments. Thus any greater variability in leaf number, within the unpricked-off treatment early in the experiment, was not evident in final leaf numbers. Some small but significant differences in cutting date and average curd diameter were established (Table V).

TABLE V
Mean curd diameter and days to cutting date

Treatment	Days from sowing to cutting	Curd diameter (cm.) at cutting date
1. Pot-grown	146.4	16.4
2. Pot-grown with drought check ..	147.5	15.1
3. Box-grown	146.5	13.4
4. Box-grown with planting check	150.2	14.4
5. Unpricked-off	151.0	11.3

Least significance difference :

P=0.05	P=0.01	P=0.05	P=0.01
3.7	6.2	2.9	3.8

There were no significant differences in cutting date between plants raised normally in pots, pot-grown plants with drought check and carefully transplanted box-grown plants, but a severe planting check to plants raised in boxes, or the omission of pricking-off from the seed box, was associated with a small but significant delay in cutting date.

Curd size was greatest with the control pot-grown plants and, although the mean curd diameter was smaller in plants of all other treatments, the difference was only significant in two cases (just significant with carefully transplanted box-grown plants and highly significant with unpricked-off plants).

The curds of unpricked-off plants were significantly smaller than those of box-raised plants given a severe planting check but the reduction in size was not significant when compared with carefully transplanted box-grown plants. It would appear reasonably probable, however, that curd size was reduced where plants were unpricked-off (and consequently remained in boxes of J.I.P.1 until planted out) as compared with those pricked off into boxes of J.I.P.3, and that the difference would have been shown to be significant had the experiment been of greater size.

Low temperature treatments

According to Whyte (1), Russian work showed that it was not possible to obtain a response to vernalisation of partly germinated seeds of *Brassica* spp., but was effective if applied to young seedlings. Miller (2) and Boswell (3) reported that exposure to low temperature was associated with premature flowering of cabbage. Peto (4) found that this was also the case with the swede turnip, and Stokes and Verkerk (5) recently reported that vernalisation of germinating seeds of Brussels sprouts was ineffective but that low temperature treatment, after a juvenile stage had been passed, was necessary for flower initiation. Carew and Thompson (6) subjected cauliflower seedlings to low temperature for three weeks and obtained decreased 'buttoning' in the mature crop and larger plants at harvest.

In the present investigation, exposure to low temperature was given at two stages, namely, germinating seeds and young plants.

A. Low temperature treatment of germinating seeds

Procedure for vernalisation : seed lots of each variety were soaked for $1\frac{1}{2}$ hours at 20°C . in distilled water to which was added a little 'Sperton' dust. After blotting and coating sparingly with 'Sperton,' the seeds were placed on sand in covered, glass dishes. Distilled water was added at the rate of 2 ml. for each 10 gm. sand. The seeds were pressed into the sand until level with the surface of the medium. All dishes were weighed and were kept at 20°C . until the radicles began to emerge from the seed coats (30 hours). The dishes were then placed in a refrigerator at a temperature of $1-3^{\circ}\text{C}$. Each dish was weighed at three-day intervals and water loss was made up by adding distilled water through a ventilation and watering tube. This tube was loosely plugged with cotton wool except when adding water.

Cold treatments were given for three weeks and for six weeks. Controls were set up as described for vernalisation but they were not placed in the refrigerator. The three weeks and six weeks cold treatments were arranged to end simultaneously. On this same day (1st June), the 30-hour period of the controls at 20°C . also finished, and the germinating seeds of all treatments were planted in boxes of J.I.P.1. There was little visible difference between the young seedlings in the various treatments ; size increased slightly with duration of vernalisation.

The boxes were stood outside and shaded with a double layer of butter muslin for the first two weeks. The plants were set out in plots on 3rd July and the mean leaf number of all varieties and treatments was then five. At four weeks after planting out there was no detectable difference in treatment leaf number within varieties but that of Pioneer was somewhat greater than that of All-the-Year-Round or Novo. Ten days later there was no detectable difference between leaf numbers of Pioneer and All-the-Year-Round but Novo still lagged behind. Caution is necessary, however, in discussing these results since the exact number of leaves produced could not be determined without dissection of growing points. It is quite possible, therefore, that Novo bore a larger number of leaves, which were smaller than 2 cm., than the other varieties.

Within each variety there was no significant difference in final leaf number according to treatment. Mean cutting dates are presented in Table VI. The only significant result was that Novo took longer to reach maturity than the remaining varieties. Low temperature treatment of germinating seeds, for three or six weeks, exerted no significant effect on cutting date when the growing period was measured from the end of the vernalising treatments. It was concluded, therefore, that chilling during germination was ineffective in hastening cutting date.

TABLE VI

Mean days from sowing of unvernalsed seeds to cutting date

Vernalisation period in weeks	Variety			
	Pioneer	All-the-Year-Round	Novo	Mean
0 	108.9	110.6	155.0	124.8
3 	101.6	111.2	143.6	118.8
6 	108.0	114.2	147.9	123.4
Mean 	106.2	112.0	148.8	122.3

Least significant difference between :		P=0.05	P=0.01
Individual treatment means	...	13.3	19.4
Variety means	}	7.7	11.2
Vernalisation period means			

B. Low temperature treatment of young plants

Seeds of All-the-Year-Round were sown on 31st March and placed in a slightly heated frame. The seedlings were potted into $2\frac{1}{2}$ -inch pots on 23rd April and low temperature treatment was started on 6th June. The plants were divided into two lots; those exposed to low temperature were placed in a dark refrigerator at $1-3^{\circ}\text{C}$. from 4 p.m. until 8 a.m. for 15 nights. The controls were stood outside and were grown in the same day-length as those subjected to low temperature. During the day, the plants in both treatments were placed side by side, and were shaded with two layers of butter muslin in order to reduce any possible devernalising effect of high temperatures.

The plants were set out in plots on 21st June. At this time the mean leaf number (over 2 cm. in length) of plants that had received low temperature treatment was 9.8 (± 0.18) and that of the controls was 10.6 (± 0.18). The difference was significant at the 5 per cent. level and indicated that exposures to low temperature slowed down the rate of leaf expansion and/or production, but these conclusions may not be justified, since the statistical analysis was performed on only 16 plants and the variable was discrete with but few possible values.

The increase in leaf number between the end of the low temperature exposures and the attainment of final leaf number was not significantly different in the two treatments but the final leaf number may have been somewhat greater in the controls ($P=0.1$ for treatment difference on the null hypothesis). The mean final leaf number was 45.2 (± 1.34) for the controls and 41.9 (± 1.34) for those exposed to low temperature. The mean number of days from sowing to cutting date, of plants that were exposed to low temperature, was 148.9 (± 0.81) and that of the controls was 153.2 (± 0.81). The advancement of cutting date accompanying low temperature treatment was small but highly significant. Thus, although there was no detectable response to cold treatment of germinating seeds, there was a small but real vernalisation effect when young plants were subjected to low temperature. These results are in agreement with those obtained by Russian workers (mentioned by Whyte (1)), and with results reported by Stokes and Verkerk (5) with Brussels sprouts.

Further work will be necessary to establish the differential responses of cauliflower varieties to time and duration of vernalisation and the effect of light during the vernalisation period.

Further evidence of a probable low temperature effect is given for the control plants of different experiments in Table VII.

TABLE VII

Mean final leaf numbers and days from sowing to cutting of
control plants from different experiments

Variety	Where seedlings were raised	Sowing date	Date from which grown unprotected in open	Final leaf number	Days from sowing to cutting
All-the-Year-Round	Heated glasshouse	5th Feb.	10th April	33.3	162.0
	In the open	19th April	19th April	34.6	114.3
	Slightly heated frame	31st March	20th May	35.5	126.9
	Slightly heated frame	31st March	28th May	38.7	118.5
	In the open	31st May	1st June	43.5	110.6
	Slightly heated frame	31st March	17th June	43.2	146.5
	Slightly heated frame	31st March	21st June	45.2	153.2
	Slightly heated frame	31st March	12th July	47.6	154.0
Pioneer ..	Heated glasshouse	5th Feb.	28th March	27.0	156.8
	Heated glasshouse	5th Feb.	10th April	25.6	156.2
	In the open	31st May	1st June	42.4	108.9
Novo ..	In the open	24th April	24th April	44.3	180.1
	In the open	31st May	1st June	33.9	155.0

The final leaf numbers and the number of days to cutting are shown, and the data for each variety are placed in order according to the date when the plants were subjected to outside conditions. Final leaf numbers of All-the-Year-Round followed this same order very closely. There was a striking positive correlation ($r=0.9405$) between final leaf number and date when plants were grown in the open. This strongly suggested that there was a temperature effect on final leaf number. It is noteworthy that the final leaf number was not correlated with the number of days from sowing to cutting. Results for Pioneer supported those for All-the-Year-Round but those for Novo did not appear to be compatible with the results for the other varieties.

Influence of high temperature

Pot-grown plants, raised in frames until 98 days after sowing, were placed in a high temperature glasshouse (70°–85°F. day and 57°–65°F. night). In high temperature, as compared with outside temperatures, plants grew taller, final leaf number was increased, cutting date was delayed and the small curds produced were very bracteate even before elongation of the inflorescence. The delay of cutting date with high temperature was much greater with small, than with large pots, and in small pots the plants were still vegetative ten months after sowing. Failure of cauliflower to head during high summer temperatures was described more than a century ago by Cobbett (7).

In another experiment it was noted that after rooted cuttings of a late variety of cauliflower had flowered and set seed in a heated glasshouse, leafy vegetative shoots were produced on the branches of the inflorescence. Results recently reported by Haine (8) confirmed some of the observations made here.

Pot size and nutrient supply

Seeds of All-the-Year-Round were sown on 31st March. The young plants were raised in a slightly heated frame in natural day-length and were grown in an unheated open frame during the summer. On 23rd April, the plants were transferred from boxes to 2½-inch pots. Some plants were potted in J.I.P.3 (a rich potting compost), and the remainder were potted in a J.I.P. compost containing no fertilisers and only a small amount of ground limestone. Some plants in each type of compost were potted on, using the appropriate potting compost, until at the fifth potting (125 days after sowing) the plants were in their final 10-inch pots. These two treatments were referred to as 'rich compost in large pots' and 'poor compost in large pots.' The remainder of the plants in rich or poor compost were potted only once, and then only from 2½-inch to 3½-inch pots. These two treatments were termed 'rich compost in small pots' and 'poor compost in small pots.'

At 83 days from sowing, there was a distinct visible gradation in size of plant according to treatment. The order in decreasing size was : rich compost in large pots, poor compost in large pots, rich compost in small pots, poor compost in small pots. Mean treatment leaf numbers are presented in Table VIII.

TABLE VIII

Mean leaf numbers

Treatment	Days after sowing		Final leaf number
	115	131	
1. Rich compost in large pots ..	25.0	35.2	47.6
2. Poor compost in large pots ..	21.8	29.0	56.4
3. Rich compost in small pots ..	18.4	21.6	45.3
4. Poor compost in small pots ..	16.5	19.2	—

Least significant difference between :	P=0.05	P=0.01	P=0.05	P=0.01	P=0.05	P=0.01
1 and 2	1.0	1.4	1.1	1.5	3.2	4.5
1 and 3, 1 and 4, 2 and 3, 2 and 4...	0.9	1.2	1.0	1.4		
3 and 4	0.8	1.1	0.9	1.2		
1 and 3, 2 and 3 ...	...	...	...	...	2.9	4.0

At both 115 and 131 days after sowing, the leaf number was different in every treatment and the sequence was the same on the two occasions. The difference between rich and poor compost, as shown by leaf number, was greater in large pots than in small pots, or in other words, the effect of pot size was more evident with rich than with poor compost. The data in Table VIII also show that higher nutrient level and greater pot size increased the rate of leaf development. The pairs of ratios given in Table IX show that the *proportional* effects of the two factors, pot size and nutrient levels, were independent of one another. Thus, for example, the proportional effect of rich compost over poor compost was almost the same in small pots as in large pots.

TABLE IX
Ratios of mean leaf numbers

Treatment comparison				Days after sowing	
				115	131
Rich compost	in small pots	..	..	1.12	1.12
Poor compost					
Rich compost	in large pots	..	..	1.15	1.21
Poor compost					
Large pots	in rich compost	..	..	1.36	1.63
Small pots					
Large pots	in poor compost	..	..	1.32	1.51
Small pots					

The final leaf number (Table VIII) was greater with poor compost than with rich compost in large pots. Final leaf numbers with large or small pots of rich compost were almost the same but the rate of development, as seen from the leaf numbers at 115 and 131 days, was greater with large pots than with small. If the rate of leaf development remained approximately constant or varied in a parallel way in the two sets during the period following the 131 days, then the time to head maturity would be greater in the small pots than in the large. Table X shows that the latter was the case. Similar effects may be expected with poor compost but the results for final leaf number or cutting date with small pots are not yet available.

TABLE X
Mean days from sowing to cutting and mean diameter of curd at cutting date

Treatment	Days from sowing to cutting	Curd diameter in cm.
1. Rich compost in large pots	154.0	10.7
2. Poor compost in large pots	163.8	4.6
3. Rich compost in small pots	190.1	1.4

Least significant difference between :	P=0.05	P=0.01	P=0.05	P=0.01
1 and 2	2.4	3.3	1.0	1.4
1 and 3, 2 and 3	2.2	3.1	0.9	1.3

In large pots, cutting date (Table X) was earlier with rich compost and the diameter of the curd was more than twice that with poor compost. With rich compost, plants in large pots were ready for cutting more than a month before those in small pots, and the curd diameter was very much greater in large pots. No large curds were produced on any plants in this experiment, however, and it appeared that the largest pots used (10-inch diameter) were still inadequate for the production of large curds. Results obtained by Winter (9) support this view.

In general, the results show that restriction of the volume of potting compost (necessarily accompanied by other changes, e.g., reduction of the space available for roots and of total available nutrients), or restriction of nutrient supply without varying the volume of compost, was accompanied by a decreased rate of leaf production, delayed cutting date, and smaller plant and curd size.

Carew and Thompson (6) reported that where plants were closely spaced in boxes, or were moved to increasingly larger pots during growth, the majority of the closely spaced plants had produced small curds after four months. Curd formation, in fact, had proceeded to about the same extent in both treatments but the curds were concealed by leaves in large pots. In the present experiment, however, large and small pots were well spaced according to plant size and in this respect the method differed from that of Carew and Thompson. Here, with small pots, curd appearance was delayed by about a month with rich compost and by more than six months with poor compost (curds had not formed at the time of writing). Results obtained by Winter (9) substantiate those obtained here on the effect of pot size. He grew cauliflower plants in pots of different sizes and all were maintained at a high nutrient level. Curd appearance was delayed with small pots.

Omission of final potting

At the final potting, a small number of plants were allowed to remain in 8-inch diameter pots. Small curds had already formed and thus the final leaf number could not have been affected. The omission of the final potting, however, was associated with a smaller curd diameter at cutting date, at any rate with rich compost. This showed that curd size was not pre-determined but was dependent on the nutrient conditions prevailing during its development.

Influence of nitrogen level

Plants were grown outside in ordinary 10-inch diameter pots filled with silver sand. The full nitrogen nutrient solution applied was one which had proved satisfactory over a number of years for growth of rye but was not necessarily an optimum nutrient solution for cauliflower. Two nitrogen levels were used, full and 1/10. Seven seeds of All-the-Year-Round were sown in each pot on 19th April. The first weekly addition of nutrients was supplied when germination occurred and the seedlings were thinned in three stages to one per pot.

From about three weeks after germination, the usual symptoms of nitrogen deficiency were observed in the low nitrogen plants. Some plants were allowed to flower and the erect habit associated with low nitrogen supply was also found in the inflorescence where the angle of divergence of axillary branches from their parent shoots was more acute with low nitrogen. Furthermore, branches remained fused for a greater distance with low, than with high, nitrogen. Consequently the width of the inflorescence was reduced with low nitrogen.

Mean leaf numbers, and cutting dates, are shown in Table XI.

TABLE XI
Influence of nitrogen level on mean leaf numbers
and mean cutting date

Treatment	Leaf number (over 2 cm. long) 102 days after sowing	Final leaf number	Number of days from sowing to cutting
Full nitrogen ..	28.3	34.6	114.3
1/10 nitrogen ..	19.8	45.1	138.3

Least significant difference: P=0.05 P=0.01 P=0.05 P=0.01 P=0.05 P=0.01
0.7 1.0 3.9 5.6 4.7 6.6

At 102 days after sowing, curds could be seen in the high nitrogen set when the young leaves were folded back but not in the low nitrogen group. The two nitrogen treatments gave significantly different effects on leaf production and cutting date. The delayed cutting date with low nitrogen was associated with the production of a greater number of leaves together with a slower growth rate. Curds were about 8-10 cm. diameter at cutting date with full nitrogen and were about half this size with 1/10 nitrogen. The latter treatment gave typical 'buttoned' plants.

These findings are supported by results obtained by Winter (unpub.). He found that nitrogen deficient plants, in sand culture, had not curded after nine months, whereas an adequate supply of nitrogen gave normal curding.

Robbins *et al.* (10) and Carew and Thompson (6) studied 'buttoning' of cauliflower in the U.S.A. Their experimental conditions differed in some respects from those described above, and they obtained some results which did not appear to agree with the present findings. The former stated that plants in the field might head prematurely if they obtained only a limited supply of nitrogenous salts. The latter found that curding was not delayed with low nitrogen.

DISCUSSION

The effects of various treatments on the growth of cauliflower have been studied by measuring leaf production at different stages. If a treatment increases the rate of leaf production without affecting final leaf number (i.e., the number of leaves produced before curd formation) or if it does not affect the rate of leaf production but reduces final leaf number, it follows that earlier heading must occur. Earlier heading would lead to earlier flowering and earlier seed formation. On the other hand, a reduction in the rate of leaf production without influencing final leaf number, or a normal rate of leaf production with an increased final leaf number, would lead to delayed heading. It was clearly demonstrated that the rate of leaf production, the final leaf number and the cutting date could be modified by suitable treatments (even although the data on leaf production were not so accurate as they might have been had apical dissection been performed).

Stokes and Verkerk (5) have shown that, with Brussels sprouts, there was a juvenile phase during which the plants could not be made to flower. This phase ended when the total leaf number was about 30. After this phase had been passed, they found that low temperature treatment followed by warm conditions induced rapid flowering. These facts may have some bearing on the results obtained here. Low temperature treatment given for 15 nights to All-the-Year-Round cauliflower plants with seven expanded leaves at five weeks after germination, produced a small but highly significant advancement of the cutting date. It is probable that there is also a juvenile phase in cauliflower as in Brussels sprouts and it may be that the small but real temperature effect obtained is accounted for by the cold treatment having been started before the end of the juvenile phase and stopped too soon. Clearly, further investigation is necessary along these lines. Indirect evidence was also obtained (Table VII) which showed that final leaf number was reduced by low temperature conditions in the open.

If a treatment which delays heading could be made more severe, the plants might remain permanently vegetative. Starvation has been shown to delay heading. The cutting date of plants at a low nitrogen level was delayed by more than three weeks and plants grown in small pots with unfertilised compost were still vegetative ten months after sowing.

High temperature also retarded cutting date of pot-grown plants by a minimum of six weeks. High temperature together with starvation gave plants which were still vegetative ten months after sowing. In those treatments where leaf counts were made, delayed cutting date was shown to be associated with a reduced rate of leaf production and/or a greater final leaf number. High temperature apparently promoted vegetative growth and this is supported by the fact that inflorescences, when subjected to high temperature, reverted to a vegetative condition.

In general, and contrary to popular belief, checks to growth did not induce the production of premature, small heads. Indeed, checks other than by a succession of cold nights were frequently associated with delayed heading, which, in turn, was usually shown to be brought about by a reduction in the rate of leaf production and/or an increase in the final leaf number. The phenomenon of 'buttoning' was not studied specifically but typically 'buttoned' plants were obtained where plants were grown to maturity in small pots, or were grown at a low nitrogen level in large pots. 'Buttoning' in the field is well known and it is possible that checks, such as by drought or by severe damage to the root system, which did not induce 'buttoning' here, might have been more effective had they been applied at a later stage or if treatment of the plants, subsequent to the checks, had not been so good.

For the plant breeder to obtain seed from late cauliflower before frosts occur, the most promising method which arises out of this work, would appear to be low temperature treatment of young plants followed by growing them on under warm conditions. The details of duration and timing of treatment have yet to be determined. If plant breeders wish to prolong vegetative growth, or convert plants from a reproductive to a vegetative condition, it seems that this can be achieved by high temperature treatment. Severe starvation also prolongs vegetative growth but gives small plants.

SUMMARY

1. The influence of various factors on vegetative and reproductive growth of cauliflower was studied.

2. Day-length was shown to have a minor effect on the time taken to produce marketable curds.

3. Some small but significant differences in cutting date and curd size were produced by the following treatments before planting out: (a) pot-grown, (b) pot-grown with drought check, (c) box-grown, (d) box-grown with planting check, and (e) unpricked off. Mean cutting date with (d) and (e) was about $3\frac{1}{2}$ days later than with the remainder. Mean curd diameter decreased in the order (a), (b), (d), (c), (e), the extreme difference being about 5 cm.

4. Where young plants were subjected to low temperature conditions, there was a small but highly significant reduction in the number of days to head maturity. Low temperature treatments of germinated seeds did not affect cutting date.

5. With high temperature, final leaf number was increased, cutting date was delayed, and curds were small and bracteate.

6. Rich potting compost with small pots, and poor potting compost with large pots, gave small curd size and delayed cutting date, when compared with plants grown in rich compost with large pots.

7. When plants in sand culture were grown at a low nitrogen level, the rate of leaf production was reduced, plant and curd size were reduced, final leaf number was increased and cutting date was delayed.

8. The possible application of some results of this work to plant breeding is indicated.

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ROTATION OF VEGETABLES WITH DIFFERENT MANURIAL TREATMENTS

By R. M. WOODMAN

This experiment was carried out on a light gravel soil at Cambridge. The land was pasture until 1934, when it was ploughed up, allowed to lie fallow for a time, and then gyrotilled and rototilled. With the subsequent heavy liming given in 1935, the land could thus be considered as being in fairly good heart. Since the beginning of the experiment, all cultivations, etc., have been done by hand.

There were 30 plots, each of seven yards square, or about 1/100 acre. Ten manurial treatments were used, five combinations of inorganic fertilisers, NPK, NP, NK, PK and Nil being applied with and without dung; three phases of the four-year rotation of five vegetables were represented. The 15 dunged plots and 15 undunged plots formed two compact blocks. The layout of the plots within the blocks followed a systematic scheme.

The experiment has lasted for sixteen years, covering four complete rotations. Owing to the absence of replication and randomisation, the validity of the standard techniques of analysis must remain uncertain. General notes on the effects of the treatments up to and including 1946 are given in (1), together with the yields for 1949-50. In this report the results of a preliminary examination of the yield trends for the sixteen years are given.

Dung was applied to the 15 dunged plots as short, well-rotted stable or farm-yard manure at the rate of 20 tons per acre, and was weighed out for each plot. At the beginning of the experiment, in the late autumn of 1934, and previous to any cropping, a preliminary dressing of dung at 20 tons per acre was given to the whole of the dunged block of plots 1D-15D to try to initiate immediate differences between the dunged and undunged blocks. The rotation was so arranged that dunged plots received dung at this rate every two years according to Table I.

TABLE I

Applications of dung*

Year	Plots receiving dung
1934	1D — 15D
1935 ; 1937 ; 1939 ; 1941 ; etc.	6D — 10D
1936 ; 1938 ; 1940 ; 1942 ; etc.	1D — 5D ; 11D — 15D.

*NPK.D plots were 1D, 6D and 11D ; NP.D — 2D, 7D and 12D ; NK.D — 3D, 8D and 13D ; PK.D — 4D, 9D and 14D ; and Nil.D plots — 5D, 10D and 15D.

The pH and lime requirements (Hutchinson—MacLennan method as lime in cwt. of CaCO_3 per acre) of the plots in 1934 are given in Table II.

TABLE II
pH and lime requirements of plots in 1934

Plot No.	Dunged Plots		Undunged Plots	
	pH	Lime requirement cwt./acre	pH	Lime requirement cwt./acre
1	6.0	23	5.8	19
2	5.5	23	5.7	25
3	5.6	23	5.4	28
4	5.9	21	5.6	30
5	6.0	17	5.7	16
6	6.0	21	5.5	19
7	5.9	21	5.4	19
8	6.0	21	5.6	16
9	6.4	12	5.7	21
10	5.6	12	5.6	21
11	5.6	27	6.5	17
12	5.4	21	6.0	19
13	5.1	18	5.5	19
14	5.7	14	6.0	20
15	5.2	18	5.4	17

TABLE III
Cropping during first rotation

Year	Plots	Crops
1935	1 — 5, 1D — 5D	Lettuce ; spring cabbage
	6 — 10, 6D — 10D	Peas
	11 — 15, 11D — 15D	Sprouts
1936	1 — 5, 1D — 5D	Spring cabbage ; carrots
	6 — 10, 6D — 10D	Lettuce ; spring cabbage
	11 — 15, 11D — 15D	Peas
1937	1 — 5, 1D — 5D	Sprouts
	6 — 10, 6D — 10D	Spring cabbage ; carrots
	11 — 15, 11D — 15D	Lettuce ; spring cabbage
1938	1 — 5, 1D — 5D	Peas
	6 — 10, 6D — 10D	Sprouts
	11 — 15, 11D — 15D	Spring cabbage ; carrots

The maximum lime requirement was thus 30 cwt. of (pure) CaCO_3 per acre for plot 4. Early in 1935, calcium hydroxide ('hydrated lime') was applied as Limbux (95 per cent. $\text{Ca}(\text{OH})_2$) to all the plots at the rate of 50 cwt. per acre ; this was equivalent to a dressing of about 67 cwt. of 95 per cent. CaCO_3 per acre, so that all plots in 1935 must have had a good excess of free lime present and, therefore, a pH just above the neutral point. The subsequent application in each rotation of four years of 20 cwt. per acre of Limbux to all 30 plots should have kept them near to pH 7 throughout the 16 years of the experiment, so that differences in yield, etc., between treatments would be unlikely to be due to differences in pH on the plots.

The rotation adopted, one consisting of five vegetables in four years, was Brussels sprouts, peas, summer lettuce, and spring cabbage followed after harvest by carrots. As previously stated, three phases of the rotation were represented, and the cropping for the first rotation period is shown in Table III.

Complete fertiliser (NPK) treatments for the five vegetables are shown in Table IV, with details of application. When N, P, or K was present in the other treatments, it was applied at the same rate as in the complete fertiliser.

TABLE IV

Fertilisers and quantities applied to the NPK plots

Crop	Fertiliser (NPK)	Dressing in cwt. per acre
Spring cabbage	Basal dressing { N = sulphate of ammonia P = superphosphate (16-18 per cent.) K = muriate of potash	1
		5
		3
	Side dressing in mid-February } N = nitro-chalk	3
Carrots	Basal dressing { N = sulphate of ammonia P = superphosphate K = sulphate of potash	1
		5
		3
	Side dressing at second hoeing } N = nitro-chalk	1.5
Summer lettuce	Basal dressing { N = sulphate of ammonia P = superphosphate K = sulphate of potash	2
		5
		2
	Side dressing just before hearting } N = nitrate of soda	2
Peas	Basal dressing { N = none P = superphosphate K = sulphate of potash	0
		3
		2
	Top dressing on coming into flower } N = nitrate of soda	1.5
Brussels sprouts	Basal dressing { N = sulphate of ammonia P = superphosphate K = sulphate of potash	2
		5
		1.5
	Top dressing during growing season } N = nitrate of soda	2

Yields are given in Tables V-IX ; in any column, yields in, say, 1935, 1939, 1943, and 1947 refer to the same plot. The yearly variation in yields is of such magnitude as to make it difficult to visualise the trends in the various treatments. By using least squares or some other method to fit year constants (2), the yields can be adjusted to eliminate mean yearly effects. The adjusted yields present a clearer picture of the trends in the various treatments, without affecting the estimates of the treatment means and slopes. The graphs of adjusted yields of three or four representative treatments for each crop are shown in Figs. 1-5. It should be noted that the fluctuations in these graphs are no longer weather effects, these having been eliminated, but represent residual error.

Although the experiment ran for sixteen years, some caution is necessary in drawing conclusions about the absolute trends of the results for any particular treatment. Thus it may be that the NPK.D yields for, say, lettuce, have been increasing for a period of years because of soil improvements following the manurial treatment, or merely because of a run of several improving 'lettuce years.' It is thus better at present to confine attention to differences in yield between the treatments rather than to consider absolute yields. A more detailed examination, e.g., of the weather factors which may have contributed to the yearly variations in yield for a given vegetable, etc., will be made by the author and Mr. Nelder during the coming year ; it may then be possible to determine what portion of the trend in yield for a given treatment is due to that treatment, and what due to weather. The curves in the five Figures are discussed below.

Brussels sprouts

Curves for the NPK.D, PK, and Nil treatments are given in Fig. 1, and are for adjusted yields eliminating year effects (2). The curves for NP.D, NK.D, PK.D, D, NPK and NK, which are omitted, lie roughly between the limits of those for NPK.D and PK ; among these eight treatments, NPK.D is generally a little above, and NK and PK a little below the remainder, but the differences are not statistically significant : thus the presence of dung has had no greater effect than the inorganic fertilisers, despite the fact that the sprout plant is usually claimed to be a 'gross' feeder, thriving on nitrogenous manures, organic or inorganic.

TABLE V
Brussels sprouts : total yield in lb. per plot

Year	Treatment									
	NPK.D	NP.D	NK.D	PK.D	D	NPK	NP	NK	PK	Nil
1935 ..	112.1	109.2	112.6	108.6	102.6	85.0	99.7	97.2	104.1	99.3
1937 ..	54.2	51.8	58.3	52.4	49.6	53.0	55.2	51.2	55.7	43.6
1938 ..	69.5	46.0	41.8	48.5	43.3	50.5	40.5	34.3	40.8	31.8
1939 ..	41.3	32.9	38.9	35.0	40.4	22.9	22.4	21.6	41.5	30.4
1941 ..	54.2	48.9	51.8	54.1	54.7	54.4	55.5	52.4	53.1	45.9
1942 ..	64.6	73.7	59.8	57.7	55.2	68.5	56.4	55.9	68.1	33.1
1943 ..	80.7	78.3	57.5	79.8	86.9	56.3	41.1	51.9	77.7	38.4
1945 ..	53.2	44.9	47.6	42.3	41.2	44.2	25.9	51.9	38.8	17.8
1946 ..	58.6	42.9	49.2	55.3	49.9	50.3	33.6	46.4	42.5	21.6
1947 ..	43.1	36.7	34.5	26.0	26.5	34.1	25.4	24.0	23.6	14.4
1949 ..	33.8	38.8	42.5	43.7	34.9	40.9	30.3	38.8	39.1	17.6
1950 ..	51.4	55.8	61.0	59.4	55.9	50.0	13.3	49.9	40.1	30.9

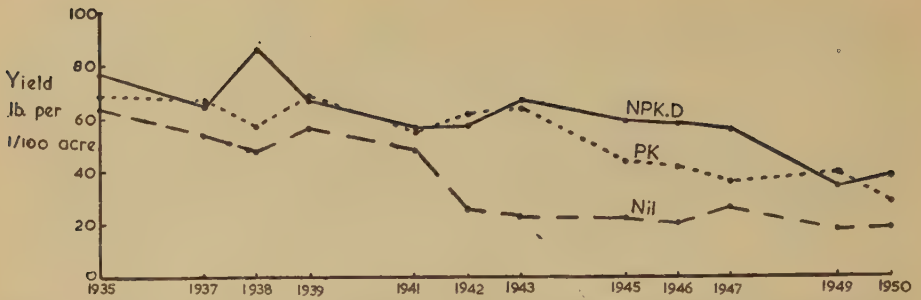


Fig. 1. Brussels sprouts. Adjusted yields (eliminating year effects) of NPK.D, PK, and Nil.

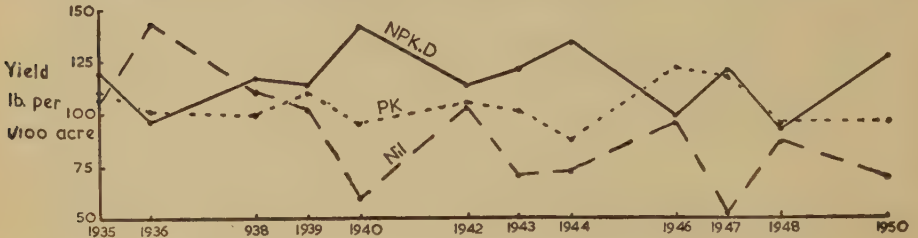


Fig. 2. Peas. Adjusted yields (eliminating year effects) of NPK.D, PK, and Nil.



Fig. 3. Lettuce. Adjusted yields (eliminating year effects) of NPK.D, PK, and Nil.

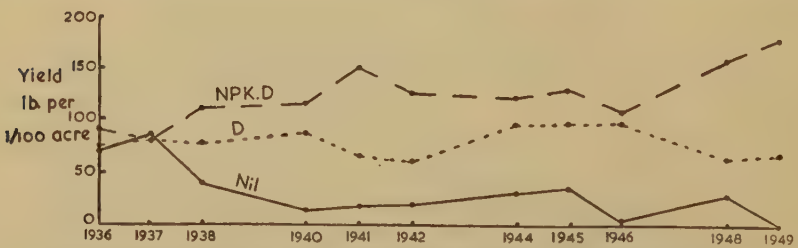


Fig. 4. Spring cabbage. Adjusted yields (eliminating year effects) of NPK.D, D, and Nil.

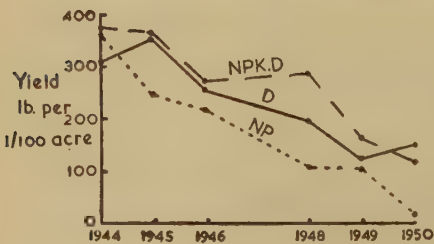


Fig. 5. Carrots. Adjusted yields (eliminating year effects) of NPK.D, NP, and D.

On the other hand, the Nil curve lies distinctly below all the others over the whole period of 16 years ; and this position, taken in conjunction with the positions of the other eight curves mentioned above, points to the conclusion that the sprout does benefit from dung and/or inorganics in some combination. The Nil curve shows a sudden drop after seven years, but the decline in yield afterwards is not greater than for the other treatments.

The NP curve (also omitted) lies generally just a little above the Nil curve, so that it might be argued that potash is the primary inorganic requirement of the sprout in this particular soil. In this connection it should be remembered that the dressings of dung on dunged plots, 20 tons per acre every two years, are equivalent on the average to an *annual* application of about 1 cwt. per acre of potash as K_2O , a quantity corresponding to approximately $1\frac{2}{3}$ cwt. of muriate of potash (concentrated 60 per cent. K_2O type). Such a dressing, even on the assumption that only half the K_2O in farmyard manure is readily available, compares favourably with the amount that many a grower would apply to most vegetables. This is probably the reason why the NP.D and D treatments lie well above the Nil treatment and between the NPK.D and PK curves ; omission of potash as an inorganic salt is evidently compensated for by the inclusion of dung.

The curves in general display a negative slope (downward from left to right) with passage of the 16 years. The cause of this, e.g., weather, a series of bad sprout years, etc., will not be considered here, but will need more detailed analysis.

Peas

Treatments NPK.D, PK and Nil are represented in Fig. 2, the yield curves being adjusted by fitting year constants (2). The PK curve shows most stability over the 16 years, and may therefore be used as a basis for reference.

NPK.D is probably slightly superior to the PK treatment. The Nil treatment is definitely the worst from 1939 onwards, but again the differences from the PK treatment are not great. The NP curve (omitted) is like the Nil curve in the later years.

TABLE VI
Peas : total yield in lb. per plot

Year	Treatment									
	NPK.D	NP.D	NK.D	PK.D	D	NP.K	NP	NK	PK	Nil
1935 ..	109.2	101.1	98.2	100.3	94.7	93.4	101.1	90.1	99.4	94.3
1936 ..	142.0	151.0	164.0	156.0	158.0	153.0	130.0	142.0	146.0	188.0
1938 ..	103.6	96.3	102.3	82.6	79.1	104.1	86.8	86.3	85.5	95.8
1939 ..	104.8	105.8	91.5	85.1	90.8	100.5	97.3	97.8	100.8	94.3
1940 ..	87.6	63.8	51.5	39.5	17.8	73.5	57.6	49.1	40.1	10.6
1942 ..	109.0	91.6	110.0	88.6	70.3	106.5	98.3	100.1	100.3	98.6
1943 ..	150.8	134.7	133.9	127.7	134.5	135.3	134.9	119.7	130.9	99.3
1944 ..	143.3	127.1	129.0	108.0	110.6	110.6	87.0	96.4	97.1	82.2
1946 ..	144.5	123.6	141.6	124.4	128.9	151.3	143.1	167.0	167.1	141.4
1947 ..	111.2	114.3	91.2	81.8	77.0	125.0	50.9	76.7	109.9	44.7
1948 ..	64.5	68.8	77.2	66.0	71.0	59.2	36.0	104.7	67.0	59.0
1950 ..	120.5	89.0	104.8	91.8	79.8	87.0	70.8	84.8	89.3	63.8

For the pea, the basal dressing did not contain nitrogen (Table IV), and was thus reduced from the usual NPK, NP and NK, where N is ammoniacal in form, to PK, P and K, e.g., the NPK plot was really a PK plot as regards the basal dressing. Nitrogen was applied (as quickly available nitrate nitrogen) only as a top dressing (Table IV), so that it was not until flowering began that the effect of NPK, for instance, became different from that of PK. Many growers omit nitrogen from their basal dressing for peas; some deliberately choose the poorest soil for exhibition peas.

Judging from the close proximity of all the curves, it seems that peas show a marked insensitivity to manurial treatment other than potash, and that, in particular, nitrogen in dung (i.e., a basal dressing of slowly available nitrogen) or in a top dressing (quickly available) has no very great influence on yield.

Summer lettuce

The lettuce yield curves, Fig. 3, have been adjusted by the ratio method (2). PK is nearest horizontal and may be taken, therefore, as the curve of reference with 'stable' yields over the whole 16 years.

Treatment NPK.D lies wholly above PK from 1936 onwards, the differences in yield between the two treatments being large, so that NPK.D is definitely superior to PK for lettuce. The Nil treatment, on the other hand, is distinctly inferior to PK and, from 1940 onwards, resulted in a negligible yield of marketable lettuce.

TABLE VII
Summer lettuce : total yield in lb. per plot

Year	Treatment									
	NPK.D	NP.D	NK.D	PK.D	D	NPK	NP	NK	PK	Nil
1935 ..	180.0	152.0	195.0	223.0	191.0	184.0	243.0	219.0	198.0	133.0
1936 ..	294.0	278.0	288.0	269.0	269.0	270.0	205.0	250.0	236.0	232.0
1937 ..	242.0	238.0	219.0	211.0	207.0	202.0	204.0	204.0	176.0	159.0
1939 ..	359.3	356.7	350.9	313.1	299.4	368.8	341.2	348.1	267.6	237.8
1940 ..	272.4	266.4	244.2	255.0	244.2	221.7	105.1	178.4	209.0	26.5
1941 ..	288.1	280.6	304.7	275.9	248.4	262.9	45.4	182.4	195.7	10.0
1943 ..	314.6	307.7	298.8	292.9	268.5	285.4	77.8	242.2	215.8	11.8
1944 ..	321.0	317.4	289.6	285.4	250.1	250.4	81.1	256.6	269.5	15.5
1945 ..	305.7	296.4	275.1	278.0	278.9	237.3	4.4	173.0	206.3	3.6
1947 ..	432.3	371.9	321.1	349.1	325.0	352.1	92.0	306.9	276.6	33.1
1948 ..	339.1	292.9	292.2	278.3	324.1	230.0	3.1	67.8	168.7	0.8
1949 ..	176.7	169.4	157.8	175.7	146.4	144.5	1.9	28.5	106.5	0.0

Of the curves omitted to avoid confusion, that for NK conforms in mean and slope to the indicator curve PK, while the NP curve is similar to and only slightly above the Nil one; it is apparent, therefore, that potash is needed by lettuce. This may be applied as potash in the inorganic mixtures NK, PK, and NPK (the curve for the latter, omitted, lies between PK and NPK.D); or as potash in dung, e.g., treatment D (curve omitted, but also lying between the PK and NPK.D curves).

The curves NP.D, PK.D, and NK.D also lie in the PK-NPK.D region.

It thus seems that lettuce responds best to dung and full inorganics, nitrogen and potash being particularly beneficial.

Spring cabbage

In Fig. 4, the yield curves for NPK.D, NK, and D, adjusted by fitting year constants (2), and for Nil, adjusted by the ratio method on D (2), are given.

The D curve for dung alone is generally horizontal in direction, indicating more or less stable yields, and provides a good reference curve for other treatments.

The Nil curve slopes downwards very steeply in the first few years (1936-40), and finally ends at zero in 1946-9, all yields from and including 1938 being much inferior to those for D. The NP and PK curves (omitted) also end up at zero, but their decline begins somewhat later than 1938.

Treatment NK gives a curve approximating to that for D (dung contains K_2O besides N) ; but NPK.D has the largest mean and the greatest upward slope, indicating that this full treatment of dung and all inorganics is superior to all others.

TABLE VIII
Spring cabbage : total yield in lb. per plot

Year	Treatment									
	NPK.D	NP.D	NK.D	PK.D	D	NPK	NP	NK	PK	Nil
1935-6 ..	85.0	90.0	72.0	83.0	68.0	79.0	77.0	66.0	68.0	61.0
1936-7 ..	55.0	59.0	57.0	61.0	55.0	73.0	74.0	64.0	66.0	60.0
1937-8 ..	101.3	88.3	86.5	69.2	66.3	73.5	58.1	75.5	64.4	32.3
1939-40 ..	112.5	108.9	121.0	80.5	84.6	71.3	78.3	69.7	33.7	13.9
1940-1 ..	148.7	119.2	120.3	87.0	63.4	74.7	87.3	58.3	34.8	15.5
1941-2 ..	209.4	222.8	217.8	170.2	142.5	168.5	85.1	159.6	134.0	32.9
1943-4 ..	132.4	123.2	117.0	116.6	105.6	112.1	95.1	112.2	90.8	38.6
1944-5 ..	98.8	82.4	91.7	88.4	65.5	63.0	54.9	58.8	43.8	28.7
1945-6 ..	130.4	139.9	148.9	137.3	121.1	137.9	0.0	127.6	91.8	3.4
1947-8 ..	168.8	155.8	155.9	111.6	74.4	136.6	115.6	93.3	57.6	25.4
1948-9 ..	133.4	82.6	82.9	54.3	24.9	107.2	1.0	51.1	0.0	0.0
1949-50 ..	17.1	24.1	5.9	3.9	11.7	63.4	4.8	23.9	15.4	0.0

All other curves, NP.D, NK.D, PK.D, and NPK (all omitted) lie between NK and NPK.D, i.e., they all give results superior to D and NK, but inferior to NPK.D.

Dung is thus advantageous to the spring cabbage, and addition of any combination of inorganics to this is increasingly beneficial. The facts that the NPK and NK treatments are at least equal to D, and that NP and PK end up by being no better than Nil, also lead to the conclusion that some mixture of nitrogen and potash is necessary to the cabbage, either in dung or as an NK fertiliser mixture.

Carrots

The yield curves for NPK.D, NP and D in Fig. 5 are derived by elimination of year effects (2), and refer only to 'Ideal' grown from and including 1944, i.e., the last two rotations. The downward trend of the three curves is a matter which needs more detailed examination than can be given here. Meanwhile it can be said that the D curve lies between the NPK.D and NP curves, with NPK.D showing superior yields.

Curves for NPK.D and D are typical of all the seven omitted curves except the Nil one. This lies somewhat below the NP one, so that the Nil treatment with omission of dung and all inorganics resulted in the lowest yields over the period considered.

TABLE IX

Carrots : total yield in lb. per plot

Year	Treatment									
	NPK.D	NP.D	NK.D	PK.D	D	NPK	NP	NK	PK	Nil
1944 ..	435.2	402.2	393.9	411.7	368.4	471.2	419.8	474.4	510.1	285.5
1945 ..	374.8	346.7	414.5	403.1	362.4	325.2	255.9	333.8	295.8	157.0
1946 ..	150.5	126.5	155.7	180.0	133.0	188.2	94.7	254.5	191.6	64.3
1948 ..	366.6	293.2	294.2	300.0	277.5	326.6	188.7	316.3	283.2	75.0
1949 ..	73.5	74.5	111.5	110.5	33.8	68.1	13.8	58.5	56.0	2.3
1950 ..	172.5	198.5	189.5	222.5	207.3	179.5	75.0	167.3	195.8	37.5

SUMMARY

1. Details are given of the treatments and layout of a sixteen-year manurial experiment on a rotation of vegetables.

2. Difficulties in the interpretation of the yield response to any given treatment over the period of the experiment are briefly discussed.

3. Brussels sprouts, in general, showed generally declining yields for all treatments over the period. The decline was very similar for the treatments NPK.D, NP.D, NK.D, PK.D, D, NPK, NK, and PK (N, P, K, D denoting application of inorganic nitrogen, inorganic phosphorus, inorganic potash, and dung respectively). Of this group, NPK.D gave yields a little higher, and NK and PK a little lower than the others. The NP and Nil yields were generally distinctly lower than the remainder.

4. Yields of peas on the whole were stable over the four rotations, except that yields from the Nil and NP plots fell off after four years. NPK.D gave the highest mean yield over the sixteen years.

5. NPK.D gave the best yield for summer lettuce, and yields from this plot showed an increase over the period of the experiment. PK gave approximately constant yields throughout the four rotations. Nil and NP yields fell after the sixth year to nearly zero. The remaining treatments gave yields between the NPK.D and PK yields.

6. Yields of spring cabbage for NK and D, though varying considerably from year to year, showed no trend during the experiment. NP, PK, and Nil gave yields which declined to zero by the end of the experiment, the decline beginning earlier with the Nil treatment. NPK.D yields showed a general increase as the experiment progressed, as also did the remaining treatments, but to a lesser extent.

7. Carrot yields since 1944 decreased with all treatments and most with NP and Nil.

The work of the above experiment during the first fourteen years was carried out while the writer was a member of the staff of the Cambridge H.R.S.

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WATERCRESS INVESTIGATIONS

By D. M. SPENCER

SURVEY OF BEDS

The survey of watercress beds begun in 1949 (1) was continued until the end of 1951. Beds in Kent were visited regularly throughout the year and those in Hampshire were kept under observation during the winter. The data collected allowed a comparison to be made between the course of crook root disease during two seasons. In March, 1951, inoculation experiments demonstrated for the first time that crook root disease was the result of root infection by the fungus which was already suspected as being the cause ; this fact was taken into account in all the subsequent work.

Weeds

A weed of watercress beds which should be added to those listed in the preceding report (1) is *Veronica beccabunga* (Brooklime). This weed is a strong competitor of watercress and should not be allowed to become established.

Virus

No watercress plants were seen with symptoms agreeing with those described by Smith (2) as resulting from infection by virus, although such symptoms were found in the previous year. In several instances, forms of interveinal mottling of the leaves were seen but it could not be said whether any of these were associated with a virus, or were due to physiological disturbance. Where this mottling occurred, it was not necessarily accompanied by stunting of the plants.

Crook root disease

Evidence of the disease in the beds was first seen in October, as occurred in the previous year, and the typical distorted roots were produced throughout the winter. The root symptom was accompanied by loss of vigour which became progressively more marked until the end of March when rapid recovery was general. Unlike the previous year, when distorted primary roots were difficult to find after the beginning of April, they could be found in some beds from April until July and apparently they had little adverse effect on the growth of the watercress during these months. It was also noted that, unlike the previous year, the root symptom was not always accompanied by down-curling of the leaf, even in the winter months. During the spring and summer months, long primary roots were produced at the lower nodes ; these bore slender secondary roots which became thickened and hooked at the tip after infection by the crook root fungus. As in the previous year, plasmodia and zoosporangia were found in all the deformed primary roots which were examined. Thus, with the longer period during which affected roots were present in 1951, these forms of the fungus could always be found in the beds, except for a few weeks in late July and in August. Plasmodia and zoosporangia were seen in the distorted secondary roots from April until July and spore balls were first noticed in July ; this was a month later than in the previous year. Spore balls were then developed in abundance until December.

STUDIES ON THE CROOK ROOT FUNGUS

Infection experiments

Successful reproduction of crook root symptoms in the laboratory was first attained in March 1951. The fungus was observed to occur only in roots and hence, in infection experiments, rootless cuttings were allowed to develop roots under controlled conditions. The standard method of producing infection in subsequent experiments was as follows. 1 lb. jam jars containing distilled water, or filtered bed water, were submerged to the shoulder in a deep sink containing water running from a tap at a rate which maintained a temperature of 12°C.-14°C. The sink was shaded from direct sunlight. Cuttings from plants grown in a non-infected bed were used for testing; these were young axillary shoots with two extended internodes (i.e., about two inches of stem) and with no visible roots. Twenty fresh, deformed, primary roots from infected watercress plants were dropped into each jar as inoculum.

After three days, new roots were visible at the nodes of the test plants and these showed kinking and distortion towards the tip; plasmodia, which later developed into groups of zoosporangia, were invariably present within five days but spore balls were never seen. The symptoms of crook root were less marked in the plants in distilled water than in those in filtered bed water.

It was found that infection also took place in August with jars on the bench over a temperature range of 12°C.-28°C., provided that they were shaded above and on three sides. In November, shading was unnecessary under the conditions of light in the laboratory. It appears, therefore, that light intensity is an important factor in producing infection. Under the above conditions infection could be obtained at will.

A replicated experiment was carried out where—(1) detritus from an infected watercress bed plus fresh diseased roots containing zoosporangia, (2) fresh diseased roots containing zoosporangia, (3) roots containing zoosporangia which had been kept at 0°C. for one week, were added to Wye main tap water, both boiled and un-boiled. No infection resulted. All other attempts to produce infection using water from the main supply at Wye, failed.

A replicated experiment, using the following treatments, was carried out to determine whether materials from watercress beds, other than fresh diseased roots, would infect healthy roots under the standard conditions of shade and temperature.

1. Water (filtered) from an affected watercress bed.
2. 1. plus roots containing zoosporangia previously kept at 0°C. for one week.
3. 1. plus roots containing spore balls previously kept at 0°C. for two months.
4. 1. plus roots containing spore balls previously kept at 3°C. for two months.
5. 1. plus roots containing spore balls previously kept at 5°C. for two months.
6. Water (unfiltered) from an affected watercress bed plus detritus from an affected bed.
7. Distilled water.
8. Distilled water plus detritus from an affected watercress bed.
9. Distilled water plus roots containing zoosporangia previously kept at 0°C. for one week.

Whereas fresh diseased roots, in either distilled water or filtered bed water, produced infection under the standard conditions, the above materials failed to produce infection.

Influence of artificial light on infection

In September, healthy cuttings were failing to produce many roots. An experiment was set up, therefore, to discover whether roots could be produced in artificial light, and whether infection would occur under these conditions, thus permitting standardisation of the infection method regarding illumination.

1-lb. jam jars were filled to the shoulder with filtered water from a diseased bed, and each jar was furnished with two healthy axillary shoots without roots and with 20 fresh, diseased roots as inoculum. The treatments, lasting for eight days and replicated four times, were as follows :— 0, 1, 4, 8, 16, 20, 23 and 24 hours per day of artificial light, the remaining hours being in darkness. Artificial light was produced by a double strip fluorescent light (Atlas 40 Watt Daylight), suspended three feet above the jars in a room where the temperature remained at $16^{\circ}\text{C.} \pm 4^{\circ}\text{C.}$

The test plants failed to produce roots under these treatments and consequently there was no infection.

The experiment was repeated in the following month of October by which time plants were again rooting easily in daylight. Plants which had eight hours or more of artificial light per day remained dark green and sturdy, developed new foliage and produced many strong roots. Those which had less than eight hours artificial light per day became yellow and spindly with little new foliage and few new roots. Infection occurred under both long and short periods of illumination.

It appeared, therefore, that eight hours of artificial light per day was necessary for good growth and that infection was not affected by the duration of artificial light of the intensity and kind used. It has already been shown that infection was apparently affected by intensity of daylight. It also appeared that rooting failure in September was not due to the intensity or quality of the artificial light. In this connection, it may be noted that during July, August and September, few roots were produced by shoots in the laboratory or by plants in watercress beds. Flowering occurs during these months and it is possible that this retardation of root production is associated with flowering.

Zoosporangia and zoospores

A study was made of the germination of sporangia using the method of infecting healthy roots as described already. Under laboratory conditions, zoospores were liberated from the newly-formed roots of the test plants eight days after the inoculum was introduced. Plasmodia were usually seen first in the non-cutinised epidermal cells near the root tip. (They were found rarely in the root hairs.) Zoosporangial groups were found in the cells of the cortex and epidermis a few days after plasmodia were seen.

Spongy spore balls

Spore balls together with sporangial groups were seen in the primary roots of plants taken from affected beds during the winter months, but the number of spore balls was relatively small. On the other hand, spore balls were preponderant in the secondary roots produced during the summer months.

In the standard method adopted for infection, the test plants bore primary roots only, and spore balls were never seen in them. The growth of secondary rootlets in the laboratory was stimulated, however, by shutting out light from the underwater parts of plants which had developed their primary roots.

The following experiment was carried out with the object of infecting healthy secondary rootlets from inoculum containing (1) zoosporangia, and (2) spore balls. Each of 12 healthy shoots, about four inches in length, and bearing primary roots about half-inch in length at the lower nodes, had their roots completely immersed in filtered water from an infected bed contained in a brown glass jar. Each jar was covered with thick brown paper to exclude all light and was kept at laboratory temperature.

The treatments, with four replications, were as follows :—

1. 20 fresh, short, deformed, primary roots devoid of secondary rootlets, and containing zoosporangia and plasmodia, but, as far as could be ascertained, no spore balls.
2. 20 primary roots, each with short, deformed, secondary rootlets containing spore balls. These roots had been incubated at 23°C. for four days in order to allow germination of any resident zoosporangia and to reduce the likelihood of the short-lived zoospores providing a source of inoculum.
3. No inoculum was introduced into the jars ; these served as controls.

After two weeks, the test plants of treatment 1 still had short primary roots but these bore distorted secondary rootlets containing plasmodia and zoosporangia. After four weeks, the secondary rootlets were moribund and contained spongy spore balls similar to those which had been seen in plants from affected beds. The test plants of treatments 2 and 3 developed long, white, primary roots having secondary rootlets about half-inch in length ; no evidence of infection could be found in these roots and rootlets.

Zoosporangia and plasmodia therefore gave infection producing zoosporangia and plasmodia which were followed later by spore balls. Spore balls gave no infection.

Several unsuccessful attempts were made to induce the germination of spore balls. When roots containing spore balls remained in beakers of water for several weeks, both root tissue and spore balls disintegrated without the latter having apparently germinated. Attempts to detect spore balls in samples of mud were also unsuccessful. These samples were obtained at intervals throughout the season from the floor of watercress beds in which crook root disease had been present in the previous year. Spore balls could not be found in the remains of old, diseased roots which had been deposited on the banks of beds.

It is proposed to describe the several phases of the fungus in a separate article.

Seedling infection experiments

In August 1951, 20 seeds of green cress were sown in each of a number of Petri dishes, on moist filter paper over a quarter-inch layer of moist, washed sand. Some dishes had their seed germinated in an incubator at 23°C. and others at room temperature. In both cases the seed germinated after three days. The seed was from the 1950 crop and gave 95 per cent. germination. The following list shows the treatments given, the inoculum in all cases being fresh diseased roots containing zoosporangia.

	When inoculated— days after sowing	Treatment after germination or after inoculation on 4th day
Inoculated and germinated in incubator at 23°C.	0, 1, 2, 3, 4	- remained in incubator. - transferred to shaded bench. - transferred to shaded sink - and cooled by running water.
Inoculated and germinated at room temperature on shaded bench	0, 1, 2, 3, 4	- remained on shaded bench. - transferred to shaded sink - and cooled by running water.

Thus there were 25 treatments, and these were replicated three times making a total of 75 Petri dishes. None of the above treatments resulted in infection by the crook root fungus but in some cases there was heavy infection by a fungus, probably a member of the *Olpidiaceae* from which the seedlings suffered no apparent ill effect.

Comparison with *Plasmodiophora brassicae*

Prompted by points of similarity between crook root disease of watercress and club root of *Brassicae*, attempts were made to infect cabbage seedlings and watercress seedlings with *Plasmodiophora brassicae* and with crook root fungus. These experiments were carried out before the method of infecting watercress with the crook root fungus had been discovered and the technique adopted was that devised by Samuel and Garrett (3). The results showed that the method for the infection of cabbage by spores of *P. brassicae* had been successfully repeated since zoosporangia were found in profusion in the root hairs of the plants. In none of the other treatments was there evidence of root hair infection, i.e., the method adopted gave no infection of watercress or of cabbage seedlings by a spore ball suspension of the crook root fungus, or of watercress by a spore suspension of *P. brassicae*. A satisfactory suspension of spores of the crook root fungus in its zoosporangial stage could not be made and hence a suspension of spore balls only was used.

NUTRITION

A sample of yellow, rather stunted watercress, but free from crook root, was obtained from a bed and two shoots of about three inches long were placed in each of several jars. The following five treatments, with four replications, were given, each jar containing 300 cc. of liquid.

1. Ferric citrate in distilled water at 0.1 gm. per litre.
2. Ferric citrate plus potassium biphosphate in distilled water each at 0.1 gm. per litre.
3. Potassium biphosphate in distilled water at 0.1 gm. per litre.
4. Distilled water.
5. Tap water.

The jars were kept in the laboratory near a south-facing window and after ten days the following results were obtained :—

- | | |
|--------------|---|
| Treatment 1. | Plants had increased about one inch in length and had produced many thick, white roots. The leaves had become green and glossy. |
| Treatment 2. | Plants had increased about two-and-a-half inches in length and had produced many long, white roots. Leaf size had increased and leaves were green and glossy. |
| Treatment 3. | Plants had increased about two inches in length and had produced many long, white roots. Leaf size had increased but the leaves were still yellow and dull. |
| Treatment 4. | Plants showed but little increase in length and there was no change of colour in the leaves which were still dull yellow. Some new roots were produced but they were thin. |
| Treatment 5. | Plants showed less growth than in any other treatment and soon became spindly. Leaves became green but soon returned to yellow. Many roots were produced but they remained short and twisted. |

It appeared, therefore, that iron restored the green colour and encouraged growth, while phosphorus and potassium together encouraged growth but did not restore the green colour.

Basic slag as a source of phosphorus, hoof and horn as a source of nitrogen, and glauconite (hydrated silicate of potassium and iron) as a source of potassium and iron, and possibly of other nutrients, were placed in watercress beds near Sevenoaks, Kent in September 1950. The cress cuttings were just beginning to produce roots but there was no sign of the disease. The previous season's crop in these beds had been affected by crook root disease so that a recurrence was considered probable. The above substances were placed in nylon bags, about nine inches by two inches, and laid on the floor of the bed so that water passing over one bag did not pass over another bag. The substances were in solid form and possessed slow rates of solubility so that small quantities would always be available to plants in the lane of flow below the bags.

The beds were visited at fortnightly intervals and crook root symptoms were first seen in early October, that is within two weeks of applying the treatments. Symptoms rapidly became general in the beds and none of the treatments apparently arrested infection of the roots. Most of the crop was harvested before mid-April and by that time treatments, other than glauconite, had produced no visible effect on the disease or on the growth of the plants. Downstream from each bag of glauconite, there was a lane, several yards in length, in which the plants bore dark green, glossy leaves instead of the curled, yellow leaves of the rest of the cress. The plants in these lanes remained vigorous throughout the winter and, even though root infection persisted, the watercress was ready for cutting about one month before the surrounding plants. (For a few weeks, short, narrow lanes of watercress below iron rods which had been laid in the beds in August, also showed a dark green colour.)

FUNGICIDES

Basic copper carbonate and home-made Bordeaux mixture paste, substances of recognised fungicidal value, were used in the same manner and at the same time as the above mentioned nutrients. Neither substance appeared to arrest infection of the roots.

VARIETAL DIFFERENCES

In August 1950, six chips of green cress cuttings were obtained from a small isolated bed near Wye, which, on frequent examination, had never shown any sign of the presence of crook root disease. They were planted in a bed at Sevenoaks which had been thoroughly cleaned and levelled following a severe crook root infection during the previous winter. The green cress was planted in two strips, each six inches wide, across the bed and the remainder was re-planted with cuttings from a bed of brown cress nearer the water source.

After six weeks, both the green and the brown cress showed crook root infection and they remained severely infected during the whole of the winter. There was, however, a marked difference between the two types, the green cress showing a strikingly more vigorous growth. During January, the brown type had thin, weak plants with heads not above water level while the strips of the green type were dense and the plants were relatively sturdy. By March, the two green strips which were originally about six inches wide had become more than eighteen inches wide.

Thus, under the conditions of the trial, green cress appeared to have a greater tolerance to infection by the crook root fungus than brown cress. This might be expected since it is generally recognised that healthy green cress is markedly more vigorous than healthy brown.

DISCUSSION

Experiments in the laboratory have demonstrated that a fungus, tentatively classified as a member of the *Plasmodiophorales*, was responsible for crook root disease. When healthy primary roots were inoculated, the fungus could be detected in the tissue of the roots within five days and zoospores were released within another three days. Thus, the cycle required only eight days in the laboratory and this explains the rapidity with which the disease is known to spread in a watercress bed.

In laboratory experiments, infection during the spring and summer months took place only when the plant was shaded from direct sunlight. This was in agreement with the course of the disease in commercial beds as recorded during two seasons; symptoms began in autumn when sunlight was reduced and there was recovery of plants in the spring with increased sunlight. The manner in which intensity or length of exposure to sunlight operates has yet to be explored.

It was demonstrated that spore balls could be produced in secondary rootlets from an inoculum of zoospores, but spore balls have never been seen to germinate. At present, the function of spore balls is unknown but the possibility that these are a long-lived form of the fungus cannot be overlooked.

Referring to control of the disease, it is questionable whether the elimination of all sources of zoospores is possible at any one time under conditions obtaining in most commercial beds. Nevertheless, the elimination of as much infected material as possible from the sides of the beds and elsewhere may delay the start of infection. The use of uninfected watercress shoots for propagation, or of cress grown from seed, is obviously important.

A suitable fungicide might be expected to kill zoospores of the crook root fungus but the problem of maintaining a continuous supply of fungicide in running water remains to be solved. Such a fungicide would need to have a low degree of toxicity to watercress plants and to fish.

SUMMARY

1. The survey of watercress beds which was begun in 1949 was continued.
2. In 1950, symptoms of crook root disease were first seen in October, and plant vigour decreased until the end of March 1951, when recovery was general. Nevertheless, primary roots containing zoosporangia were to be found until September except for a few weeks in late July and August.
3. Zoosporangia were first seen in secondary rootlets in April and spore balls in July.
4. A method of infecting healthy primary roots of watercress in the laboratory was found. Zoospores were released from the freshly infected roots within eight days from introducing the inoculum. No spore balls were formed.
5. The intensity of daylight was a controlling factor in the infection of healthy roots. Inoculation was successful under either short or long periods of exposure to fluorescent lighting.
6. Secondary rootlets were developed in the laboratory and these were inoculated with zoospores. Plasmodia and zoosporangia developed in the rootlets after two weeks and spore balls after four weeks.
7. Tests were carried out in infected commercial beds to study the effects of certain nutrients and fungicides. Of these, glauconite increased the vigour of the plant; the others showed no promise.
8. Watercress of both the brown and the green types were shown to be badly infected by the crook root fungus, but the green type was more tolerant.

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STATISTICS REPORT

By J. A. NELDER

It has been agreed that the statistical section of the N.V.R.S. shall be responsible for assisting the N.A.A.S. Experimental Horticulture Stations and, so far as commitments allow, other outside bodies, with statistical problems arising from work on all horticultural crops other than fruit. In consequence the writer has advised on the planning of certain Dutch-light and glasshouse experiments for the Experimental Horticulture Stations, and has analysed the results from the first experiments on lettuce made by these Stations. During the year, advice on experimental layouts and assistance with analyses of results have been given also to Ditton Laboratory of the Department of Scientific and Industrial Research in connection with the deterioration of market produce in transit, and to the Nottingham University School of Agriculture concerning experiments on the pricking-out of seedlings.

Work for the N.V.R.S. has included assistance to other members of the staff in planning and analysing experiments, and a paper has been prepared on the analysis of a field experiment where fixed manurial treatments were applied to a rotation of vegetables (1). Theoretical and practical studies on the genetics of continuous variation, begun during the year, are described below.

Polygenic variation

It has become almost commonplace to say that genetics has not helped the plant breeder quite as much as some geneticists had hoped. The reason for this has been clear for some time. Geneticists have been mainly concerned with the study of characters showing discontinuous variation which are governed by so-called major genes and, unfortunately, these characters are usually of no economic importance. Plant breeders, on the other hand, deal mainly with characters, such as yield, vigour, hardness, etc., which show a continuous variation between extremes. It has long been postulated that these characters are the combined expression of a complex of hereditary factors, whose effects are not separately distinguishable. The determination of the structure of such genetic systems, usually known as polygenic systems, presents new problems of analysis and interpretation.

An attack on these problems has been made by Mather (2), who considers particularly the analysis of the variation shown by the successive generations following the crossing of two true-breeding lines. It was decided to carry out experiments of this kind on a vegetable and also to consider some theoretical aspects of their analysis. The vegetable chosen was the French Bean (*Phaseolus vulgaris* L.), and two varieties, Hurst's Negro Longpod and Cambridge Countess, have been selfed and crossed. Negro Longpod has relatively large elongated black beans while Cambridge Countess has small, nearly round white beans. These varieties were chosen because of their contrasting characters and because they showed an unusually small amount of variation in these characters, which might be taken as an indication of their true-breeding nature. The variation was particularly small in seed characters such as length, weight, etc., and it was intended to use these as variables for analysis. In crossing and selfing, flowers were enclosed in small pieces of muslin attached by pins. Unfortunately, crosses with Cambridge Countess as female parent set no seed, and very few seeds were obtained for the reciprocal cross. It may, therefore, be necessary to replace Cambridge Countess with some other variety in the projected experiment.

On the theoretical side, certain variance components defined by Mather have been worked out in more generality, and an investigation is in progress on the statistical models used in this branch of genetics. It is hoped to publish papers on these two topics shortly.

Other work

A note on the statistical independence of quadratic forms in the analysis of variance, has been published in *Biometrika*.

REFERENCES

- (1) NELDER, J. A. (1952). The analysis of a field experiment with fixed manurial treatments applied to a rotation of vegetables. *Ann. Rep. Nat. Veg. Res. Stn.*, 1951, 71-6.
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THE ANALYSIS OF A FIELD EXPERIMENT WITH FIXED MANURIAL TREATMENTS APPLIED TO A ROTATION OF VEGETABLES

By J. A. NELDER

Sixteen years' data from a field experiment, carried out by R. M. Woodman and summarised in (1), are now available. In this experiment ten fixed manurial treatments were applied to a four-year rotation of vegetables. Some methods of analysis applicable to this type of experiment are considered here.

The considerable yearly variation in yields can be eliminated, at least in part, by fitting year constants; such a procedure, however, can only be applied where the average yields over the period are of the same order. When one or more treatments are of the 'exhaustion' type, where yields fall sharply after an initial period, the hypothesis of a constant year effect is clearly untenable. In this case, a year effect proportional to the mean is more plausible. A further difference between the 'exhaustion'-type treatment and those giving near-stable or slightly increasing yields over the period is that, while a linear trend may describe the latter well enough, the former are likely to show a non-linear trend of sigmoid type.

We consider first the analysis of the yields from a set of treatments of the 'non-exhaustion' type. Table I gives the yields, to the nearest pound, of six treatments for the lettuce crop in the rotation. Since the experiment contained only three phases of the four-year rotation, lettuce is missing in one year out of four.

TABLE I
Lettuce yield in lb. per plot of 1/100 acre

Year	Treatment						Total
	NPK.D	NP.D	NK.D	PK.D	D	NPK	
1935	180	152	195	223	191	184	1,125
1936	294	278	288	269	269	270	1,668
1937	242	238	219	211	207	202	1,319
1939	359	357	351	313	299	369	2,048
1940	272	266	244	255	244	222	1,503
1941	288	281	305	276	248	263	1,661
1943	315	308	299	293	269	285	1,769
1944	321	317	290	285	250	250	1,713
1945	306	296	275	278	279	237	1,671
1947	432	372	321	349	325	352	2,151
1948	339	293	292	278	324	230	1,756
1949	177	169	158	176	146	144	970
Total	3,525	3,327	3,237	3,206	3,051	3,008	19,354

Three components of variance may be distinguished, the treatments $\times$ years interaction, the variance between plots within years, and the variance of successive yields of the same plot after eliminating the treatments $\times$ years component. We denote these three components by σ_1^2 , σ_p^2 , and σ^2 respectively. For the data of Table I the analysis of variance takes the following form in the absence of trends.

TABLE II
Analysis of Variance

Component	D.F.	Expectation of mean square
Years	11	
Treatments	5	
Treatments $\times$ years : plot means ..	10	$\sigma_1^2 + 4\sigma_p^2 + \sigma^2$
Treatments $\times$ years : within plots ..	45	$\sigma_1^2 + \sigma^2$
Total	71	

The first component of the interaction term is based on the totals of the successive yields from the same plot, and the second component is the remainder. In an unreplicated experiment it is not possible to separate σ_1^2 and σ^2 .

Since the data in Table I come from an unrandomised experiment, errors obtained for the means are suspect, but those for linear trends will be less so. Each component of the interaction sum of squares will provide an estimate of the slope; let these estimates be b_1 and b_2 for the plot-mean component and within-plot component respectively. The most efficient estimator of the slope will then be

$$b = \frac{w_1 b_1 + w_2 b_2}{w_1 + w_2} \quad \text{where } w_1^{-1} = \frac{\sigma_1^2 + 4\sigma_p^2 + \sigma^2}{S_1} \quad \text{and } w_2^{-1} = \frac{\sigma_1^2 + \sigma^2}{S_2}$$

S_1 and S_2 being the sums of squares of the independent variable in b_1 and b_2 respectively. In practice, of course, we shall have to replace w_1 and w_2 by their estimates from the analysis of variance, as is done in a similar situation in incomplete block analyses. Provided that w_1 and w_2 are based on sufficient degrees of freedom,

this is not a serious matter. In the particular case when $\sigma_p^2 = 0$, $b = \frac{S_1 b_1 + S_2 b_2}{S_1 + S_2}$

and is the estimate obtained by regarding all the yields as independent.

To apply this analysis to Table I, we need two subsidiary tables, one giving the total yield for each plot over the four rotations and the other giving the total yields over each rotation period for each treatment. These are given below.

TABLE III
Total yields of plots over four rotations

	NPK.D	NP.D	NK.D	PK.D	D	NPK	Total
1st year ..	1,286	1,189	1,166	1,178	1,084	1,190	7,093
2nd year ..	1,226	1,154	1,114	1,087	1,087	972	6,640
3rd year ..	1,013	984	957	941	880	846	5,621
Total ..	3,525	3,327	3,237	3,206	3,051	3,008	19,354

TABLE IV
Total yields per rotation period

	NPK.D	NP.D	NK.D	PK.D	D	NPK	Total
1st rotation ..	716	668	702	703	667	656	4,112
2nd rotation ..	919	904	900	844	791	854	5,212
3rd rotation ..	942	921	864	856	798	772	5,153
4th rotation ..	948	834	771	803	795	726	4,877
Total ..	3,525	3,327	3,237	3,206	3,051	3,008	19,354

To avoid constraining the year constants differently in the two estimates of b , we shall consider the estimation of slope *differences* only and apply the constraint $Sb=0$. The primary analysis of variance, corresponding to Table I is given in Table V.

TABLE V
Primary analysis of variance

Component	S.S.	D.F.
Years	215,379.28	11
Treatments	14,855.95	5
Treatments $\times$ years : plot means ..	4,188.80	10
Treatment $\times$ years : within plots ..	18,705.25	45
Total	253,129.28	71

The sum of squares for slopes from Table III is given by $(1286-1013)^2/8 + (1189-984)^2/8 + \dots + (1190-846)^2/8 - (7093-5621)^2/48 = 1903.17$, and from Table IV by $[(-6) \times 716 + (-2) \times 919 + 2 \times 942 + 6 \times 948]^2/240 + \dots + [(-6) \times 656 + (-2) \times 854 + 2 \times 772 + 6 \times 726]^2/240 - [(-6) \times 4112 + (-2) \times 5212 + 2 \times 5153 + 6 \times 4877]^2/1440 = 4,079.22$. The analysis of variance is now as in Table VI.

TABLE VI
Analysis of variance

Component	S.S.	D.F.	M.S.
Years	215,379.28	11	—
Treatments	14,855.95	5	—
Plot means { Slopes ..	1,903.17	5	—
{ Remainder ..	2,285.63	5	457.126
Within plots { Slopes ..	4,079.22	5	—
{ Remainder ..	14,626.03	40	365.651
Total	253,129.28	71	—

As we should expect, the plot-means-remainder mean square 457.126 is larger than the within-plot-remainder mean square 365.651, but the estimate of σ_p^2 is only $(457.126 - 365.651)/4 = 22.869$, which is insignificant in comparison with the remainder. It is sufficient, therefore, to take the simple slope with weights $-7, -6, -5, -3, -2, -1, 1, 2, 3, 5, 6, 7$. This gives for relative slopes the values

NPK.D	NP.D	NK.D	PK.D	D	NPK
2.68	1.31	-1.48	-0.46	0.31	-2.37

and the standard error of any difference is

$$\left(\frac{2 [8 \times 457.126 + 240 \times 365.651]}{248^2} \right)^{\frac{1}{2}} = \pm 1.724$$

Although the weighted estimate of b is an unnecessary refinement here, an example will be given, using the treatments NPK.D and NPK, in order to demonstrate the method. The estimate of slope difference b_1 is obtained from Table III and is $b_1 = (1013 - 1286 - 846 + 1190)/8 = 8.875$. From Table III, we find $b_2 = [-6(716 - 656) - 2(919 - 854) + 2(942 - 772) + 6(948 - 726)]/240 = 4.925$. Now $w_1 = 8/457.126 = 0.0175006$ and $w_2 = 240/365.651 = 0.6563636$, from which the weighted estimate b' ,

say, is calculated as
$$\frac{(8.875 \times 0.0175006) + (4.925 \times 0.6563636)}{0.0175006 + 0.6563636} = 5.028 \text{ with a s.e. of}$$

$$\left(\frac{2}{w_1 + w_2} \right)^{\frac{1}{2}} = \pm 1.723$$

The gain in accuracy here is entirely trivial, and there is the added disadvantage in the weighted method that w_1 is based on only 5 degrees of freedom and so is rather poorly determined.

The estimation of absolute slope

The estimation of absolute slopes for the treatments raises questions about the structure of the year constants. The simplest hypothesis would be to regard them as forming a random sequence. The difficulty lies in finding a sensitive test of randomness when only a short series of yields are available. In fact, unless there is a very strong cyclical component or lag-correlation, no test will show a significant deviation from randomness in the series. Perhaps the best solution lies in finding what climatic factors, if any, can account for most of the yearly variation. If such factors can be found, then a regression technique can be used to standardise the yields to some 'mean' climate. It should be noted that in postulating the existence of σ_1^2 in the model, we are assuming that the *differential* effects of the yearly weather on the treatments are effectively random, although we do not assume that the *average* effects are also random. To what extent this is a more plausible hypothesis than that of completely random effects is a matter which cannot be decided without much longer series of experimental data than are at present available, at least in the sphere of horticulture.

There is another possible source of deviations from randomness in the year constants which is only indirectly dependent on the weather. This is the negative serial correlation which might arise if poor yields in one season tended to be followed by good yields in the following season owing to the availability of greater quantities

of nutrients left over from the previous year, and *vice versa*. This might be a factor to be considered in an experiment with a perennial crop or with repeated use of the same annual crop : in a rotation, however, the yields of any crop on the same plots are separated by several years, and such an effect in the yield series of any particular crop can be discounted. There remains the possibility that some variation of a crop may be accounted for by the variation of the previous crop grown on the same plot, although a preliminary examination of Dr. Woodman's data shows little indication that this is so.

The analysis of 'exhaustion'-type treatments

In the lettuce yields in Dr. Woodman's experiment, two treatments, NP and Nil, showed yields which fell abruptly after several years and then remained low, sometimes sinking to zero. Clearly a model employing year constants cannot be used here. A proportional year effect is likely to give a better representation of the effects. Such year effects cannot be fitted by least squares, however, unless the trend form is also assumed to be known. As previously pointed out the straight-line trend is likely to fail here, and some kind of sigmoid, the mirror-image of the growth-curve type, is more plausible.

If information is required on the shape of the trend curve, some smoothing may be done if one of the other treatment series shows little or no trend. In such a case, each yield of the 'indicator' series can be expressed as a proportion of the mean yield of that series, and the yields of the series which it is desired to investigate are multiplied by the inverse of these proportions to give the adjusted yields. Symbolically if x is a yield of the 'indicator' series and $\bar{x}$ is the mean of this series, the adjusted value y' of the corresponding yield y of another series is given by $y' = y \cdot \bar{x}/x$.

For its validity, this method obviously depends on the non-existence of a trend in the 'indicator' crop and a proportional year effect between the two crops. As an example, we may take the Nil series from the lettuce data with the NPK series as the 'indicator'. The relevant calculations are shown in Table VII.

TABLE VII
Adjustment by the ratio method

Nil y	NPK x	$\bar{x}/x$	$y' = y \cdot \bar{x}/x$
133	184	1.3623	181.2
232	270	0.9284	215.4
159	202	1.2409	197.3
238	369	0.6793	161.7
26.5	222	1.1291	29.9
10.0	263	0.9531	9.5
11.8	285	0.8795	10.4
15.5	250	1.0027	15.5
3.6	237	1.0577	3.8
33.1	352	0.7121	23.6
0.8	230	1.0899	0.9
0.0	144	1.7407	0.0

$$\bar{x} = 250.6667$$

If the adjusted yields are plotted and compared with the original yields, it will be found that the regularity in the former is considerably more marked than in the latter, and that the sigmoid form emerges more clearly.

SUMMARY

1. In the analysis of a field experiment with fixed manurial treatments applied to a rotation of vegetables, the estimation of the relative slopes in treatments where linear trends are fitted, is considered.

2. Some difficulties in the estimation of absolute slopes are discussed.

3. A simple method of smoothing the yield curves of 'exhaustion'-type treatments is proposed, for use in cases where the previous analysis cannot be applied.

Acknowledgment is due to Mr. H. D. Patterson for helpful discussions.

REFERENCE

- (1) WOODMAN, R. M. (1952). Rotation of vegetables with different manurial treatments. *Ann. Rep. Nat. Veg. Res. Stn.*, 1951, 52-60.

THE WEATHER DURING 1951

By G. A. PURDY and E. J. WINTER

Under the Agricultural Meteorological Scheme of the Air Ministry Meteorological Office and the Ministry of Agriculture, a Crop Weather Station has been set up at the National Vegetable Research Station, and regular observations were started on 1st October, 1950.

The instruments are read daily at 0900 hours G.M.T. They include a sunshine recorder, anemometer, and maximum, minimum, grass minimum, wet bulb, and dry bulb thermometers. Earth thermometers are installed at 4, 8, 12, 24 and 48 inches deep. The instrument readings are supplemented by regular eye-observations of the condition of the soil surface, local weather, visibility, wind and clouds.

Observations from October 1950 to December 1951

Fig. 1 shows the monthly mean earth temperature at depths of 4 and 48 inches. The temperature at 48 inches lags behind that at 4 inches, both in spring when the soil is warming up, and in autumn when it is cooling down. Fig. 1 also shows the monthly minimum temperature immediately above short grass, and at 48 inches above ground. From October 1950 to May 1951 there were ground frosts on 105 nights. (In accordance with the usual convention, 'ground frost' was recorded when the temperature fell below 30°F.). The month with the greatest number of ground frosts was December 1950, when there were 28, the most severe of which occurred during the night of the 5th (grass minimum temperature 3°F., i.e., 27 degrees of frost). Nevertheless, at no time during the 15 months was the soil found to be frozen to a depth of 4 inches at 9 a.m. Air frosts (recorded when the temperature 48 inches above the ground fell below 32°F.) occurred on 82 nights during the winter of 1950-51. The first was on 25th October and the last on 30th April. The most severe air frost was on 6th December when there were 18 degrees of frost.

Fig. 2 shows the average daily rainfall, sunshine and run-of-wind for each month from October 1950 to December 1951. The driest months were June, July and October (both years), and the wettest were August and November (1951). In 1951 there was almost as much sunshine in April as in the peak month of June.

The run-of-wind (Fig. 2) is the apparent number of miles travelled by the air in 24 hours. At Wellesbourne, the anemometer is mounted only two metres from the ground, at which height movement of the air may be expected to have a greater effect on vegetable crops than at the standard height of 10 metres. In 1950, the months with most wind were April and November. On 29th January, 1951, at a height of two metres, there was complete calm for 24 hours.

Fig. 3 shows the number of wet days (.01 inch of rain or more) for each month. In February and March 1951, and again in August and November, two-thirds of the days were wet. In contrast, October was very dry in both years.

Fig. 4 shows the total rainfall during each month and, for comparison, the long-term average at Shottery Hall, a station six miles from Wellesbourne. Total rainfall at Wellesbourne during 1951 was 30.39 inches, 22 per cent. above local average.

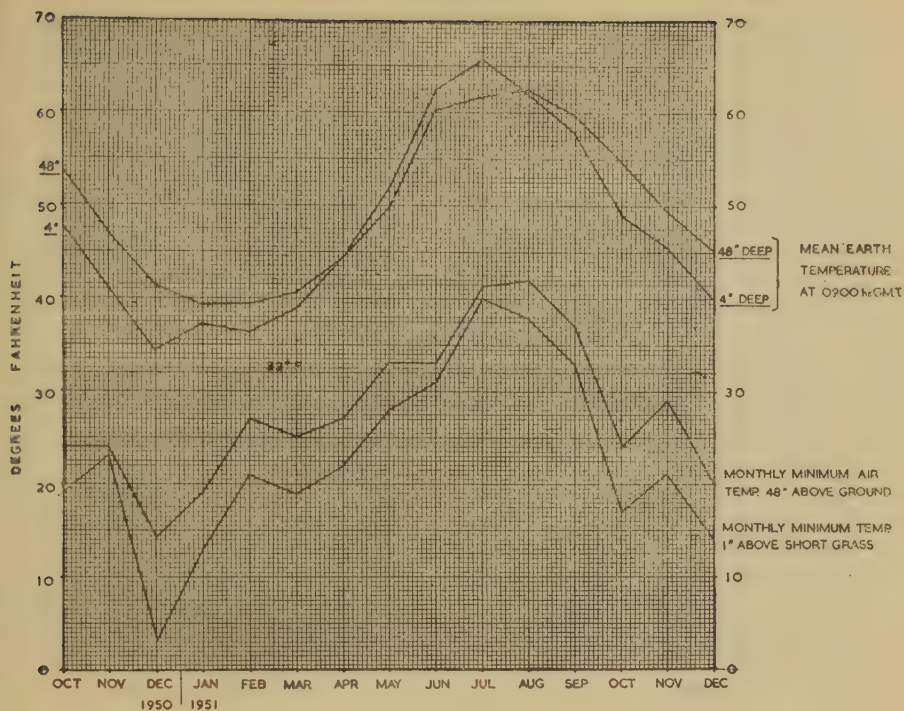


FIG. 1 TEMPERATURES AT N.V.R.S. CROP WEATHER STATION

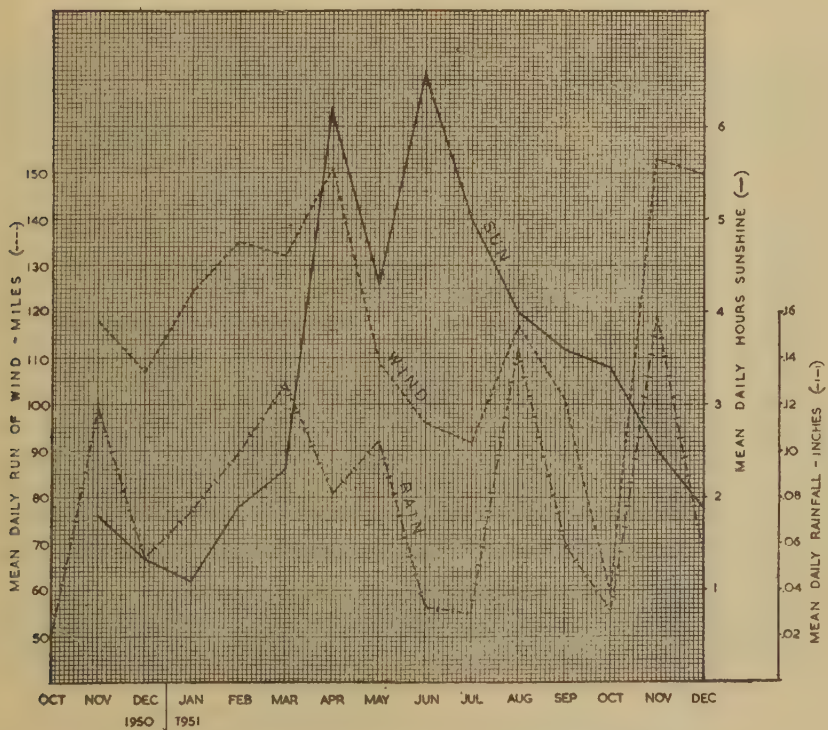


FIG. 2 MEAN DAILY SUNSHINE, RAINFALL AND RUN OF WIND

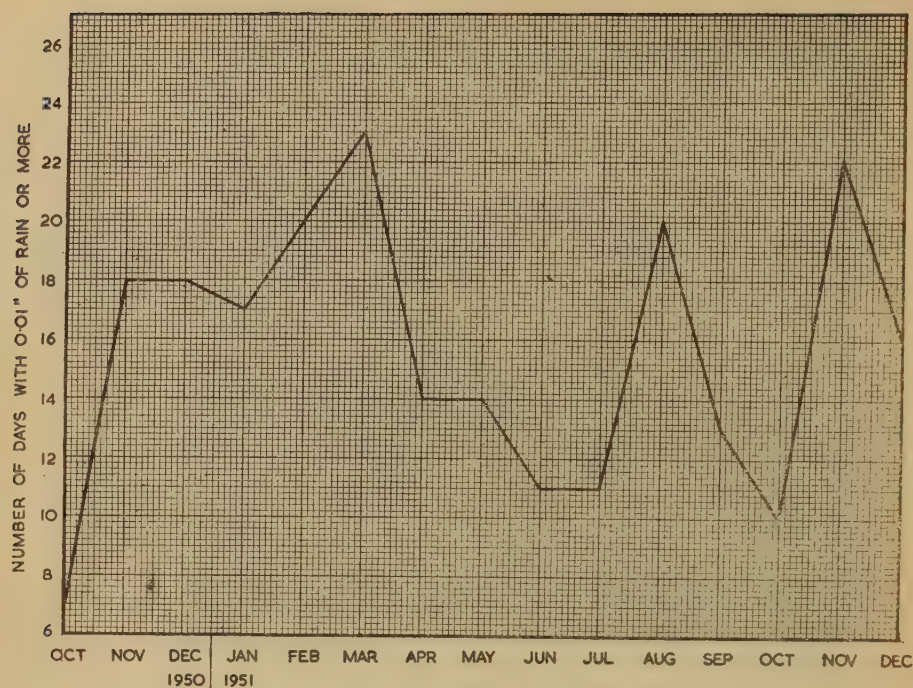


FIG. 3 NUMBER OF WET DAYS PER MONTH

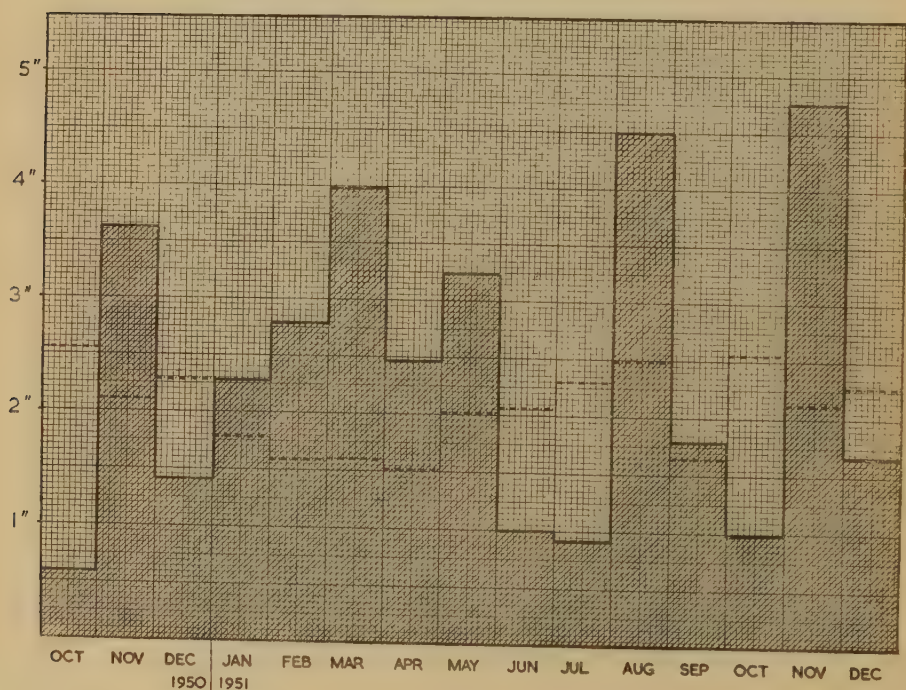
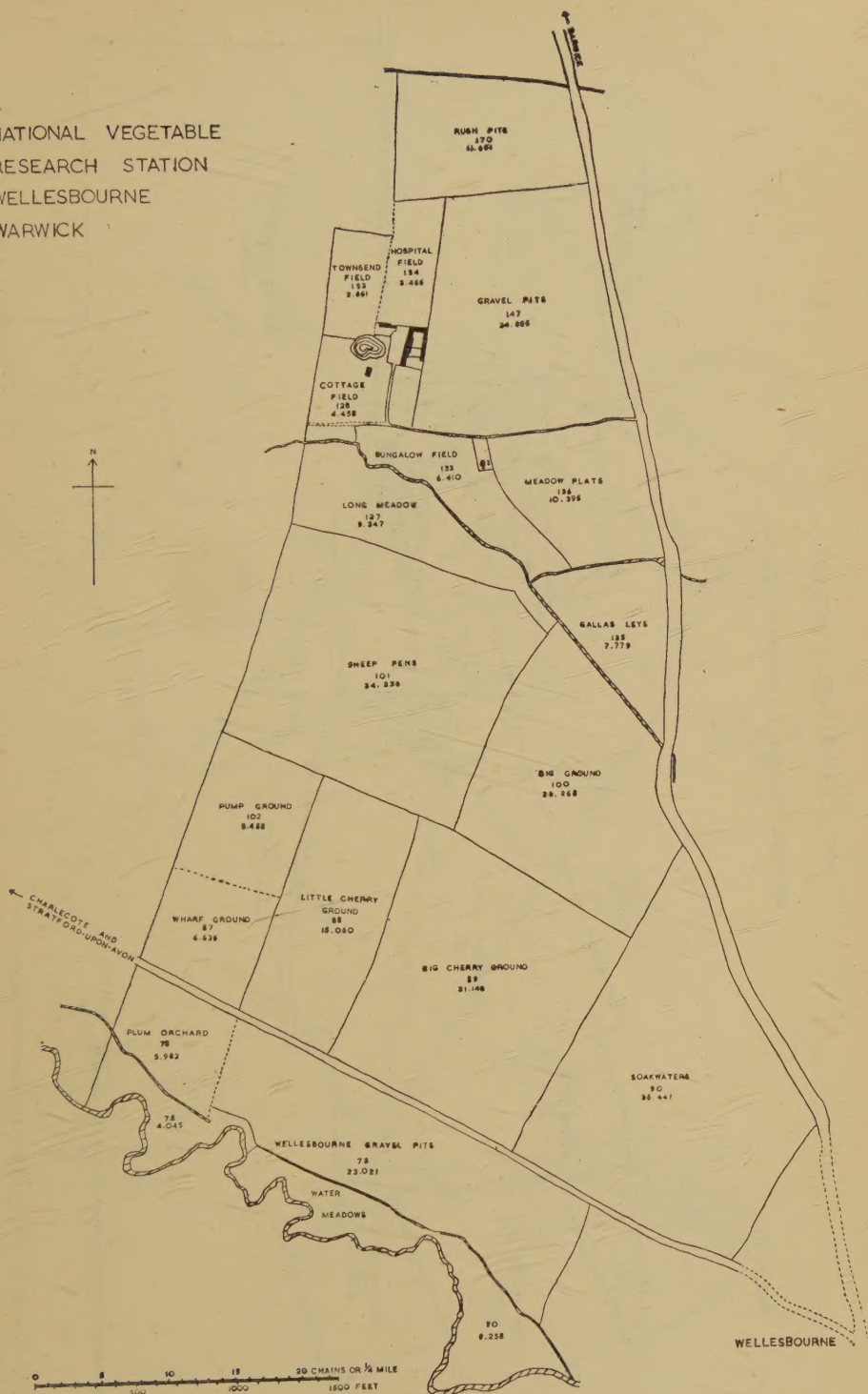


FIG. 4 TOTAL MONTHLY RAINFALL

Dotted line shows long term average at
Shottery Hall, 6 miles from Wellesbourne.

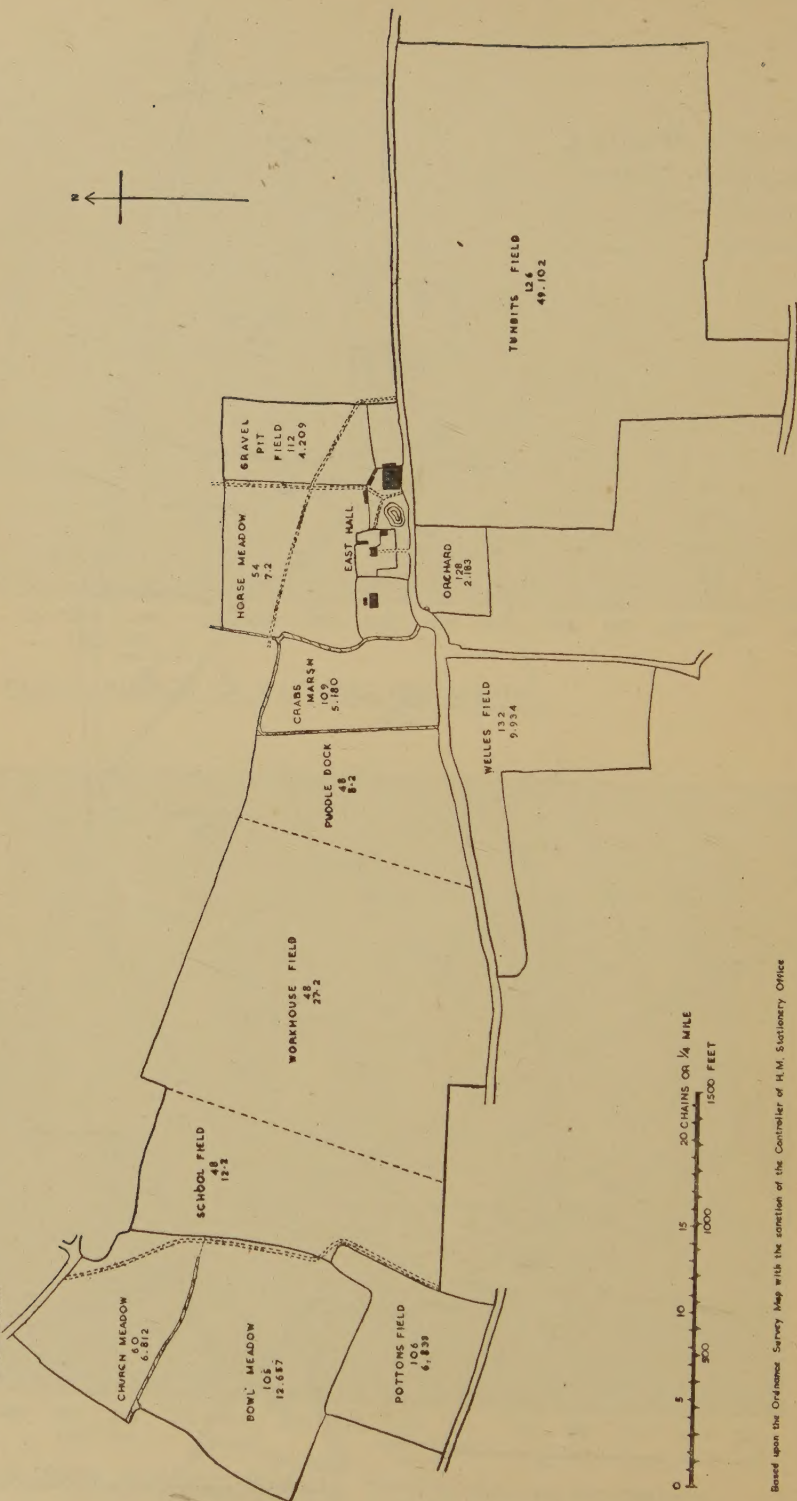
NATIONAL VEGETABLE
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WELLESBOURNE
WARWICK



Based upon the Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office

PAGLESHAM SUB-STATION OF THE NATIONAL VEGETABLE RESEARCH STATION

PAGLESHAM



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